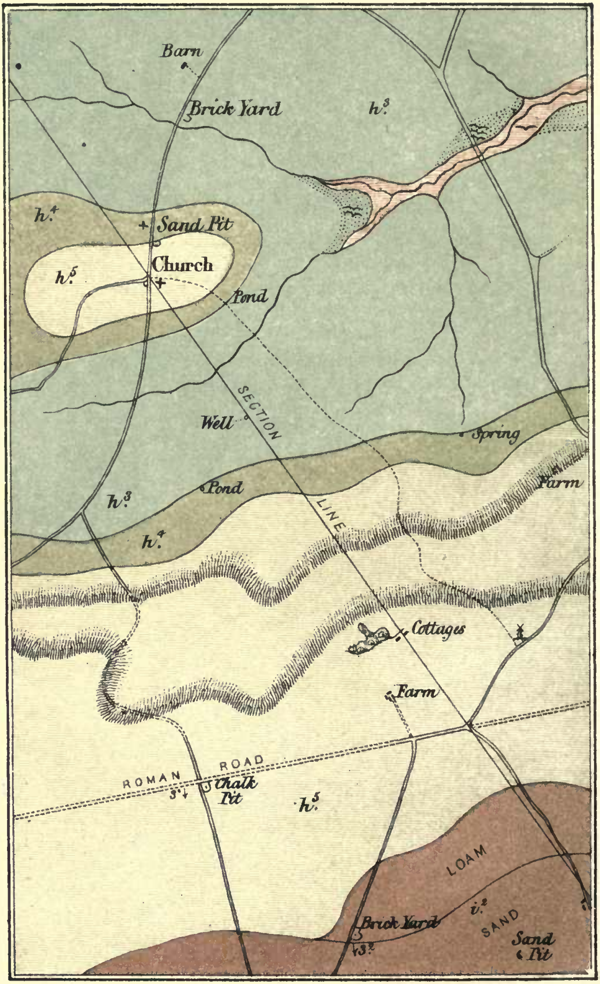
FRONTISPIECE.

Scale 1½ inches to 1 mile.



h^3.	GAULT.	h^4.	UPPER GREENSAND		ALLUVIUM
h^5.	CHALK	i^2.	READING BEDS		BRICK-EARTH
					GRAVEL.

FIELD GEOLOGY.

BY

W. HENRY PENNING, F.G.S.,

Geologist,

H.M. GEOLOGICAL SURVEY OF ENGLAND AND WALES.

WITH A SECTION

ON

PALÆONTOLOGY.

BY

A. J. JUKES-BROWNE, B.A., F.G.S.,

H.M. GEOLOGICAL SURVEY.

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1876

THIS WORK

Is Affectionately Dedicated

TO

MARIANNE,

THE WIFE OF THE AUTHOR.

PREFACE.

THE first idea that suggested itself to me, in regard to a work of this kind, was to publish a few plain instructions for drawing geological boundary-lines, a practical matter which seemed to have been somewhat neglected, although it is of considerable importance.

But there is an almost imperceptible transition from mapping rocks, which appear at the surface of the earth, to tracing those that are beneath, and from defining the extent of a formation to the determination of its history, as expressed in its lithological character and fossil remains.

The idea, therefore, while being realised, expanded to much beyond its original dimensions, still there is scarcely any portion of the book in which the matter might not, with advantage, be enlarged. It has, however, been thought advisable to issue, as it is, this first edition, and leave for a second (should it ever be required) any further extension.

There are so many subjects of which a knowledge is an advantage in geological surveying, that it is difficult to say what ought not to be included in a book on Field Geology. The object aimed at has been to include herein those that are absolutely necessary, in as small a compass as is consistent with the purpose in view.

My colleague, Mr. Jukes-Browne, was good enough to undertake the section on Palæontology, at a time when, unfortunately, his state of health was not as good as could be desired. For this reason the list of characteristic fossils following his work was not prepared by him, and it is, perhaps, far from being as complete, and probably as accurate, as it would otherwise have been.

The new rules for finding direction of true dip, when first published in the *Geological Magazine* for May 1876, gave rise to some useful criticism; it was then too late to make any alteration in the text or the figures, but a footnote has been inserted to give the resulting modification.

W. HENRY PENNING.

CALDECOTE, CAMBS.
August, 1876.

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FIELD GEOLOGY.

INTRODUCTION.

It may fairly be claimed for Geology that its advance has been more rapid than that of any other science. From the time of William Smith—the Father of English Geology—until now the number of those who take interest in the subject has been steadily increasing. Every year sees the birth of some new periodical devoted to Geological Science; every list of new books is sure to contain the name of one or more bearing directly or indirectly on the questions with which it deals, and it possesses already a most comprehensive literature. It plays a prominent part in University and and other public examinations, where, until recently, it was all but unknown; and it guides, as it ought to guide, the direction of mining and other practical operations. With many the study is taken up as an amusement or a pastime, and is found to possess a fascination peculiarly its own; it opens up to the more philosophical student a fair field of investigation; and presents to all many interesting physical problems for thought and speculation

As the number of geological students increases, the greater is felt to be the need of a Manual which shall teach the *practical* procedure in the field and elsewhere. A great majority of the manuals of Geology, although excellent as guides to a theoretical knowledge of the science, do not sufficiently describe the *methods of observation in the field.* Without such proper method much time is wasted, many results that otherwise would have been valuable are entirely lost, and the student finds that his labours do not yield to him a proportionate amount of beneficial knowledge.

To facilitate the acquirement of such knowledge, this work has been published—not as containing very much that is original, but as embodying in a small compass practical directions and suggestions which are to be found here and there only in more important works. The object has been to bring them—with some additions which are the result of practical experience—into a form which shall be at once portable and adapted to special reference.

If we would make a series of drawings that shall shew the geological structure of any district, it is not sufficient that we are versed in theoretical geology, nor even that we can walk into a quarry and say, "This is a Limestone," or a "Sandstone"—as the case may be—and "it belongs to this or that Formation." We must be able to trace out its boundary, to shew the area that it occupies, and to ascertain the angle at which it dips beneath the surface. When these points are determined in regard to a series of strata, we have a geological *Map*, or surface projection—and aided by our notes, we can construct therefrom a geological *Section*, which shall shew the underground extension of the rocks, their thickness and their relative positions. By its general appearance, and by the aid of simple tests in the field, or if necessary, more complicated ones applied to detached specimens at home, we ascertain the *kind* of rock of which any bed or series of beds consists. By this means, and by the determination of the Fossils collected from such bed or series of beds, we are enabled to assign to it its position as belonging to a certain formation, or possibly even to a definite horizon in such formation.

Thus we see that, to obtain an accurate knowledge of the structure of a district, to represent and describe its geological features, and to be able to generalise therefrom, four distinct and different, although intimately connected, operations have to be performed. The strata which crop out at its surface must be traced, and their boundary laid down upon the map. The dip (if any) and the underground continuation of the beds worked out—the character, peculiarities, and geological age of the rocks ascertained, and their fossil contents discovered, determined, and classified. Each will be treated of separately as far as possible, under one of the following heads—

1. Geological Mapping.
2. Sections.
3. Lithology (*Determination of Rocks*).
4. Palæontology („ „ *Fossils*).

The directions given in each Part will be simple and elementary, assuming the student to possess a fair book-knowledge of the science, of its theory, of the sequence of the various systems, formations and groups, and of the general succession and range of fossil plants and animals. By giving examples of the method in its simpler applications, the chances of confusion or misapprehension are greatly lessened—at the same time suggestive hints are inserted, which indicate, rather than describe, the more detailed and complicated operations and calculations.

Additional notes are given on the more common Minerals, Metals and their Ores—their mode of occurrence, and the methods adopted for their discovery and utilisation. Also on the Rocks which do not follow the general laws of stratification and arrangement, requiring therefore a somewhat different method of ascertaining and shewing their extent and their relations—these are the eruptive and intrusive rocks and the glacial deposits. A short sketch is added of the practical application of geological surveying, in the important question of water-supply from deep-seated springs.

PART I.

GEOLOGICAL MAPPING.

CHAPTER I.

MAPPING AND INSTRUMENTS.

Maps—Contour Maps—Compass and Protractor—Hammer, Pick, Spud, &c.—Scales—Tracing Boundaries—General Propositions.

Maps.—In tracing and mapping geological boundary lines, it is very essential to have as good as possible a map of the district to be surveyed. One that is not tinted and not closely covered with the names of places, for the fewer these are in reason the better—but on which such prominent objects as churches, windmills, and so on are shewn with fair typographical accuracy. The physical features should be rendered as distinct as may be, by the insertion of all rivers, brooks, and water-courses; and if there be hill-shading, drawn with even an approach to accuracy, it will be an improvement; and heights above the sea-level given in figures here and there are a great advantage. Maps drawn to a scale of *one inch to a mile* will generally be found the best for the purpose; they are sufficiently large to admit of the main features being correctly shewn, and a sheet representing many square miles can be carried and referred to without inconvenience. If great accuracy be required—as in the out-crop of Coal-seams, for instance—it is well to go at once to maps drawn on a *six inch* scale, although they may be in some respects inconveniently large. For the plain spaces thereon between roads and hedges admit of the frequent notes necessary in such cases being written on the map itself, instead of in a book specially provided —no trifling advantage when the size of the map to be carried is taken into consideration. The maps of the Ordnance Survey, especially those issued during the last few years, are as good as any; in choosing copies, those should be selected which are clear and distinct as regards the engraved lines, but which are light rather than dark impressions.

Contour Maps.—Some maps have marked on them certain lines, the meaning of which it is well clearly to understand; these are called "contour lines." To the eye accustomed to them, these lines convey at a glance the physical geography or the actual "shape" of a tract of country—its hills and valleys, its precipices and ravines—and not only in a sketchy or approximate form, but with heights and depths taken from actual admeasurement. A contour line runs through all the points at which a perfectly horizontal plane at any given height would intersect the surface of the ground; in other words, if the land were covered with water to a certain height, the margin of the water would be exactly represented by a contour line drawn at that same elevation. These lines are shewn for every 10, 25, 50, or 100 feet, according to the scale of the map and the degree of accuracy required. In geological surveying they are of assistance in the drawing of boundary lines, ascertaining heights and making various calculations.

Note.—All maps are laid down on the paper with reference to the *true meridian*, the proper allowance having been made in their compass bearings for the magnetic variation—at the present time in these Islands the needle points about 22° West of due North.

Compass and Protractor.—It frequently happens that it is necessary to identify on the map one's exact locality, when the roads, fences, &c., shewn thereon do not afford sufficient indication. For this purpose a Compass is used; an ordinary pocket compass of fair size will suffice in most instances, and will give very nearly the position of the place at which it is used; but for greater exactness a prismatic compass is necessary. The latter is not quite so easily carried as the pocket compass, although the small prismatics now made and fitted in sling-cases are very portable, and a Protractor also is required to plot the result of an observation.

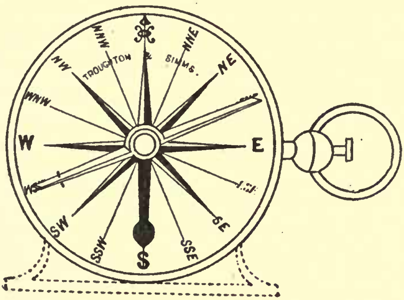


Fig. 1. Compass and Clinometer.

The pocket compass (fig. 1) generally has its circumference divided into 16 parts—the 4 cardinal points, the 4 intermediate, which divide the cardinals, as N.W., &c.,

and 8 others sub-dividing the spaces between the cardinal and intermediate points, as N.N.E., and so on. To determine a locality, the needle must be set free, and the instrument held perfectly level in front of the observer, and between him and the distant object on which he takes a bearing. It must then be turned steadily round, until the needle comes to rest 22° to the left or West of North. At the same instant the eye, being carried from the centre of the compass to the object and back again, will detect the point in the circumference on a line from the object to the observer. This reads off perhaps N.E., or half-way between N. and E.; this would be represented on the map by a line, in such a position as to lie mid-way between two others, one vertical for N. and S., the other horizontal for E. and W. direction. A scale or pencil laid across the object on the map in such mid-way position affords a means of drawing a pencil line that corresponds with the bearing taken. The observer is situated at *some point* along this line, and by repetition of the observation on another object (as nearly as may be at right angles to the first) he gets a second line crossing it at a point which represents the required position. If E.N.E. had been read off, half-way again between N.E. and due E. would give the direction, and the same method of course applies to all the other points in the compass.

The prismatic varies from the pocket compass in having its circumference divided into 360 degrees, instead of into cardinal and intermediate points; and in being provided with sights for taking more accurate observations. The needle carries with it a nicely balanced card on which the divisions are marked, the figures thereon being reversed so that the prism (which inverts the rays passing through it) presents them to the eye in their proper position. The card is, or ought to be, so attached to the needle that proper allowance has been made for magnetic variation. To take a bearing, the needle must be liberated, the vertical sight erected, and the prism pulled up to suit the eye of the observer. The instrument is then held up to the eye, being kept as level as possible in the hand, and directed to the object from which the bearing is being taken, until the card shall have gradually ceased to revolve.

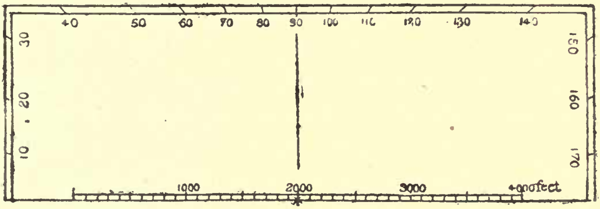


Fig. 2. Protractor, upper side (half size).

The division then seen immediately beneath the vertical wire records the number of degrees subtending the angle contained between the line of bearing and the true N. and S. meridian. The number of degrees count to the *right* of due N.; thus E. reads 90°, S. 180°, W. 270°, and N. itself 360°, the complete circle. In plotting the line of bearing therefore the protractor (fig. 2) must be laid on the map to the right of the object, the centre of the semi-circle which it represents resting directly thereupon and its inner edge parallel (as near as the eye can judge) with the margin of the map—that is, due N. and S. A point is now marked on the paper at the number of degrees corresponding with that read off in the compass and a line drawn through this point and the object gives the first bearing. A second line is then found to cross the first, the nearer the angle between them is to a right angle the greater the accuracy of the result.

> *Note.*—As the protractor represents but *one half* of the circle it will be necessary when the number of degrees read off exceeds 180 (the total shewn thereon) to plot that number and begin again—or, what is the same thing, to deduct 180 from the degrees indicated and commence from the other end, that is, with the protractor placed on the *left-hand* side of the object.

It sometimes occurs that one bearing is sufficient for the purpose: *e.g.* when the spot is situated *somewhere* on a road or fence-line shewn on the map, but with nothing to shew its more exact position. Another and a ready method of spotting one's locality where there is no lack of known landmarks is to place on the ground a stick, or a hammer, directed to an object; then to look along the stick from its other end and note the object with which, or near to which, it is in line. This gives a fair bearing in one direction, and if it be crossed by another, as with the compass, the position found on the map is not far wrong.

Hammer, Pick, Spud, &c.—To draw a geological line, it is necessary to have at hand some means of ascertaining what strata run up to the surface in any locality that is to be geologically mapped. There is always—with very rare exceptions—a depth of surface soil varying from 2 or 3 inches to 2 feet or even more, beneath this is frequently found a subsoil consisting of the disintegrated upper portion of the rock on which it rests. To ascertain the kind of rock, these, or at all events the former, must be penetrated.

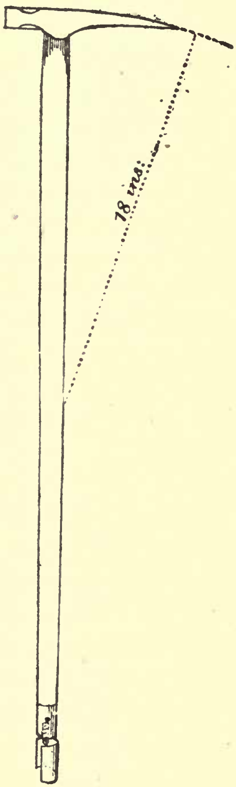


Fig. 3. Hammer, Pick, and Spud combined.

Almost every one who follows geological pursuits has a hammer to suit his individual fancy, and so long as it is capable of breaking up a good-sized stone its fashion is immaterial. But for the purpose of drawing lines it will be found convenient to have the tail of the hammer drawn out into a chisel-pointed pick, 3 or 4 inches in length, with a slight downward curve (fig. 3).

With such a pick one can easily dig down through a foot of surface soil, or cut away the face of clay and sand in pits, banks, and cuttings. Its outer side should be bent into a curve described by a radius, 1 foot in length for a pocket hammer, and 18 inches for one with a long handle such as would answer also for a walking-stick. Some prefer boring to digging through the soil—this is done by a gouge-like spud attached to the lower end of a stick or a long hammer-handle; it can be either removable or permanently fixed. This, when pressed into the earth and screwed round, will make a hole from a foot to 2 or 3 feet deep, according to the hardness of the material, and bring up cores as specimens from the bottom. In figure 3 is represented a combined hammer, pick, and spud; with the latter unscrewed the hammer does duty for a walking-stick, and altogether it is as useful and portable a set of implements as can be carried by a Geologist.

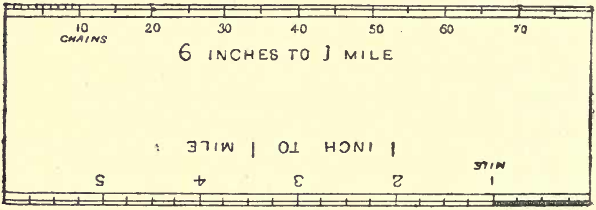


Fig. 4. Protractor, underside as scale (half size).

Scales.—For the purpose of measuring distances on the map a scale is required, the most useful size being 6 inches long. The carrying another instrument may be saved by having the reverse side of the protractor divided (fig. 4), on the one edge into 80 parts for use with the six-inch maps, each part representing a chain. The other edge, for use with the one-inch maps, must be divided into inches, and each inch into 40 parts representing 2 chains: smaller sub-divisions would be too minute. The otherwise plain edge (on the degrees side) of the protractor may with advantage be divided for a part of its length into feet, on the scale of 6 inches to a mile—it will be serviceable for plotting or measuring from sections (fig. 2).

Tracing Boundaries.—A geological map is one which defines the area occupied by the denuded edge, or upper surface of each formation, where it comes to the level of the ground. To accurately construct such a map, therefore, every part of the ground must be more or less minutely examined. If by any means, as by boring or otherwise, the surface of an area were to be proved at say every 100 yards and the varying results shewn by different colours, a geological map would be roughly presented. But it would be an approximation only, for there would still remain to be shewn the exact position between the borings where the *lines of division* run. In Chapter II. it is intended to explain how such lines may be traced and represented on the map to be geologically tinted.

> *Note.*—In speaking of "boundary lines," those are meant which bound a formation, which describe its lower margin, and, in fact, indicate its extreme occurrence in any direction. Its upper edge, where it first appears at the surface, is called its "line of outcrop," and this of course corresponds to the boundary line of the overlying formation.

If a certain set of fields on one side of a road, fence, or brook, shewn on the map, were entirely on one formation, and another set of fields on the opposite side were entirely on another formation, then the engraved line would answer also for that of the geological division. But it rarely happens that the arbitrary lines of a road or fence follow the intricate windings of a natural division of the rocks. With a brook the case is somewhat different, it being frequently found that brooks and water-courses work their way back along such planes of separation.

For the sake of constant reference it is best to have the plain copy of the map, which is to be geologically coloured, cut up into slips of convenient size, say 6 by 4½ inches. They may be secured by bands within the pages of a note-book or pocket map-case. Six-inch maps must be used in larger sheets carried in cases slung from the shoulder. If the slips are cut all to one size, they can afterwards be mounted on linen to fold in the usual manner.

General Propositions.—The following three propositions, if remembered, will be of material assistance :—

1. *The boundary lines of horizontal strata exactly coincide with the contours.*

   This must be the case, however uneven the surface of the ground where the outcrop occurs.

2. *The boundary lines of strata dipping towards a hill are less winding than the contours.*

   This is evident if we consider that were the dip to be gradually increased until the strata were vertical, the lines of outcrop would gradually approach, and finally become parallel straight lines. Therefore, as the dip into a hill, so the line varies from a contour towards a straight line.

3. *The boundary lines of strata dipping from a hill are more winding than the contours.*

   This is just the reverse of Prop. 2, for were the dip increased until equal to that of the surface slope, the boundaries would run in parallel lines down the flanks, and until the slope varied could not meet. But the proposition is true to a certain point only—when the dip, in this direction, *exceeds* that of the slope, the boundary lines, in this case also, begin to draw in towards a straight line, which they must eventually attain to if the dip increased until the strata were vertical.

Strata sometimes occur in a horizontal or nearly horizontal position. It is evident from Prop. 1, that if we can once fix a point through which passes the boundary of such a stratum, a contour line drawn from this point will accurately represent the boundary so far as its horizontality is continued.

Much more frequently we find strata dipping into the higher ground from beneath which they have risen to the surface. Indeed, this may be considered the normal position of stratified rocks now forming dry land, as their dip has itself given the initial form to the hills above them. In this case any points at the same level on the line of strike must be on the boundary—assuming its passing through one of them to have been ascertained. A line following the curves of the contours, but flattened in proportion to the dip (Prop. 2), represents accurately the line required.

It is an exceptional occurrence for strata, at their outcrop as opposed to 'dip-slope,' to dip with the slope of the ground. When this does occur, the line of junction must be ascertained in several places, and the points united by exaggeration of the contour (Prop. 3).

Contours run in a V-like shape up the valleys, in straight lines on flanks and ridges, and sweep round the outline of the hills—their variations are as numerous as the hills themselves, but this kind of form prevails in

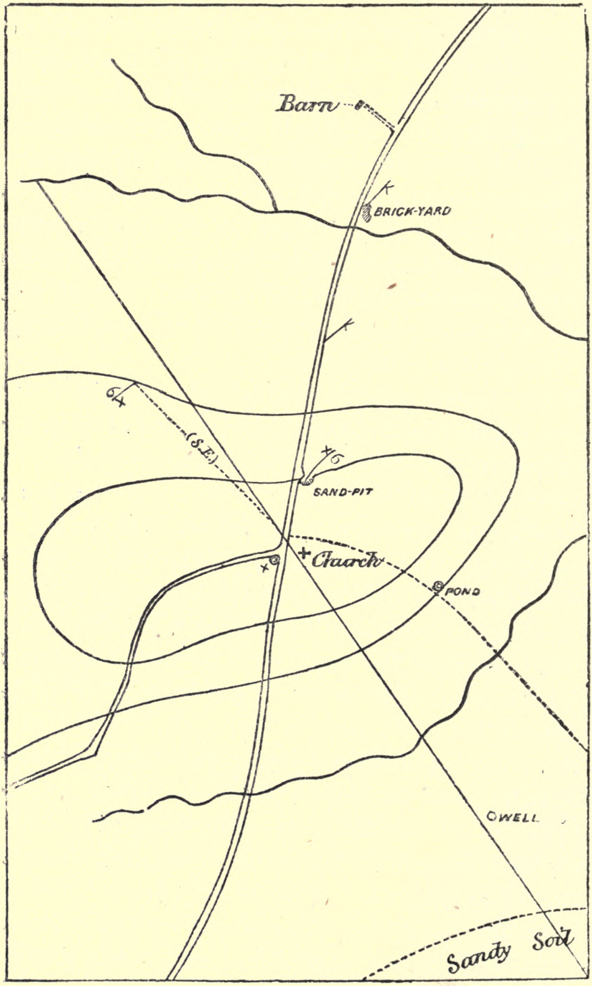


Fig. 5. First Slip.

all. (See some excellent remarks on, and illustrations of, this subject in Sir Charles Lyell's "Students' Elements of Geology," p. 60 [1871].)

The above are general ideas which it will be well to have impressed on the mind, as in tracing a boundary their principle will yield immense assistance. Of course in practice the ground must be gone over, and the actual line followed, for dip may change anywhere, and it often does so in places where it is least expected. Faults also may occur, and these interrupt suddenly the continuity of a line, and involve a fresh one of their own.

CHAPTER II.

MAPPING (*continued*).

Examples of Tracing Boundaries—Memoranda—Traversing—Symbols—Drift Deposits.

Examples of Tracing Boundaries.—Having then procured a map of the district to be surveyed, cut it into two slips to fit the map-case, and provided ourselves with compass, scale, hammer, and so on, we will proceed to the actual work before us. The slip represented by fig. 5 (but of course without the geological lines thereon) is to be the scene of our operations, and we start, in imagination, from the church, which, we are inclined to think from the white appearance of the soil hereabouts, stands on the Chalk formation. By an examination of the pond on the other side of the road this supposition is confirmed, for the excavation has been made three or four feet deep, and its sides here and there exhibit sections of that well-known rock. We note this fact by a symbol of some kind—a small x will do—marked on the map where the rock is exposed, that is, at the pond.

Proceeding along the road to the N. we find an old pit, nearly overgrown, which turns out to have been formerly worked for sand. By picking about in all likely places we discover that sand is not the only thing in the pit, for its upper part on the S. side is really in chalk. We clear away the soil with our pick, making a clean-cut trench, and soon get an actual junction of chalk and sand, the former overlying the latter. This is a grand find, and one that will not frequently be made in practice—as sand-pits are made for the sake of sand only, and chalk-pits for the chalk—it happens rarely, and then by accident, that pits and quarries are opened on the line of junction. On the map we indicate the occurrence here of chalk over sand, by the chalk symbol x over another (for instance σ) for sand, with a short line between: thus $\frac{x}{\sigma}$.

> *Note.*—The method of observation, and the notes made of this and other exposures of the rocks, and of facts relating thereto and otherwise obtained, are described in Part II.

The boundary of the chalk of course passes through this pit; accordingly we draw a short line across the road in that position, and which will be presently prolonged. We now continue our walk in the same direction, but see nothing worthy of remark except that clay is visible in a newly-cut ditch about half-way down to the brook—this is indicated by another symbol, $\varkappa$, at the spot where it is observed. Evidently we have come off the sand, but nothing as yet points out the line of boundary, and its discovery may be for the moment deferred.

We should expect to find below the Chalk, the Upper Green-sand, and below this the Gault clay; probably we are now on the latter formation, but of this we cannot be certain without further evidence. There is a brick-yard on the other side of the brook, and the pit there from which the clay is taken affords ample material to justify our coming to that conclusion.* Looking northwards the gault clay forms a nearly level flat of rich pasture land extending apparently beyond the margin of our map.

On retracing our steps we observe in the distance an excavation of some kind, a good way off on the W. side of the road, and thereto we make our way. It proves to be a trench dug for a drain, at one part of which clean gault is turned out, and a little higher up, sand. The junction is close by, not exactly visible anywhere, but it must be between the two places, and we can here commence our line. But where are we? Away from the road, the brook, and everything else on the map. Now the compass comes into requisition, and we at once take a bearing on the church, it reads S.E., and we draw a pencil line accordingly.† Taking a second bearing on the barn away to the northward, we get another line crossing the first at our exact position. Here then begins the line, and here also seems to be a slight alteration in the slope of the ground, the gault makes almost a flat to the N., the sand rises more rapidly to the S., the change of feature due evidently to the difference in the strata.‡ Our line must be drawn as nearly as may be where this change occurs, which seems to very nearly follow the contour of the ground,

* Post, p. 55. † Ante, p. 8. ‡ Post, p. 28.

it crosses the road between the sand-pit and where clay was observed in the ditch. Beyond the road this feature becomes less distinct, but we draw the line as a contour from the shape of the ground, of course it sweeps round to the right up the other valley, and just where it crosses the footpath there is a pond. Here we can get no direct evidence, but may fairly assume that thus far our line is correct, for the pond would be about on the junction—dug through the sand which yields water into the clay by which that water is upheld. Continuing the contour it takes us across the road, which offers no evidence other than a slight change in inclination, and on to the lane beyond; here, by picking in the banks, we get sand in one place, clay in another just below, and between the two runs the line of boundary.

So far this is satisfactory, and we return to follow the chalk line, the commencement of which was afforded by the sand-pit near the church, but in passing up the lane we find out by aid of the pick, and we mark on the map, where it will be crossed by the chalk boundary. From the sand-pit we draw a contour as before, getting here and there in the ditches a little evidence to check our work, round the point, across the footpath and the main road, through the spot marked in the lane, and on by the form of the ground. Here the line would seem to turn back as it were upon itself, and to end where it began, in the sand-pit; it really does so, and the chalk we have mapped thus is proved to be an "outlier." We walk over the ground on the S. side of the brook, but find no open sections, in all the ditches clay is visible except at the extreme S.E. corner, where the soil is very sandy. A well has been sunk at a spot which we mark on the map, and is stated to be 110 feet in depth.

> *Note.*—Almost every bank where the road is in cutting and every ditch of even moderate depth will yield evidence of the kind required, when the fallen soil and rubbish have been cleared away. But in picking into a bank, in spudding at the side of a ditch, or in cutting at the face of an exposed section, care must be taken to get at the actual stratum beneath the vegetable soil. In the absence of ditches, trenches, and banks (and there are many bleak spots bare of all such aids), we must pick or bore through the surface soil here and there on either side of the probable line of boundary, look out for the heaps of stuff thrown out from their holes by moles, rats, and rabbits—these often afford useful hints in an obscure area—and last, but not least, we must accustom our eye to judge from the soil itself what is the rock which lies beneath, in other words, from which it has been derived.

At home the lines should be permanently drawn with Indian or other ink that will not run with wash of colour; the brickyard, the sand-pit, and the section-symbols inked in, and the pencil lines of bearing, &c., erased; the spaces between the lines may then be tinted in any colours selected for the different formations.

Let us now take in hand another slip, fig. 6. Here we start perhaps at the S.E. corner, which is on chalk, for that rock is seen in a small pit at the back of the farm, and the ditches by the roadside. The ground is comparatively high here and overlooks a broad flat to the N. which is traversed by a fair-sized brook. In

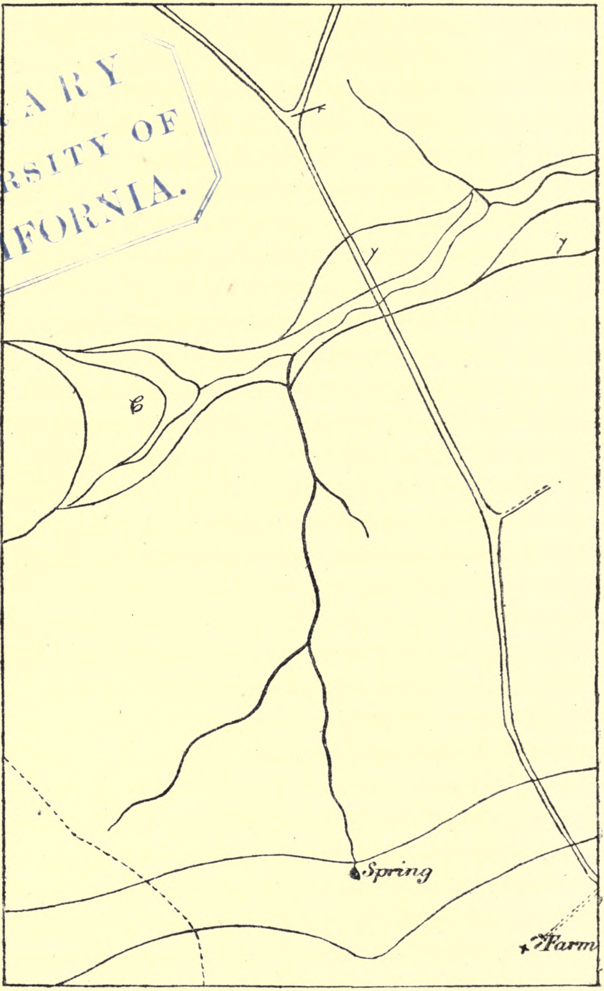


Fig. 6. (Second Slip.)

passing along the road, and after losing the whitish soil of the chalk, we find, first sand, then a little farther on gault clay; no good sections, but still sufficient to enable us to draw short lines where the road is probably crossed by the boundaries. Once on the clay, we see nothing else until we approach the stream, which runs through flat marshy ground that appears to be quite level. This flat marshy ground is "river alluvium," and as such must be mapped—a very easy matter, which consists mainly in drawing a line where the slightly sloping surface of the gault is lost in the level of the alluvium. A contour line it is in fact, and necessarily so, seeing that this alluvial deposit is the result of deposition from the flood waters of the river which has occasionally overflowed its banks. This line is best drawn in walking along it, or nearly so, down one side of the stream and up the other; it is found to run a little way up the smaller streams and to die out just before we reach the W. margin of the slip.

A clean section of the gault is seen in a pit by the roadside, on the N. side of the river, but no other evidence, although we walk over the flat at the N.W. corner and down the W. side, until we strike the footpath when gault is again visible. Following the footpath, at the rising ground we come upon sand, note approximately the junction, and a little higher up find by digging that the sand passes in under the chalk. It is now a matter simply of continuing to draw these two boundaries, the lower one passes through a spring, by which the general accuracy of the work is proved, and both cross the road where we had drawn the short provisional lines soon after starting.

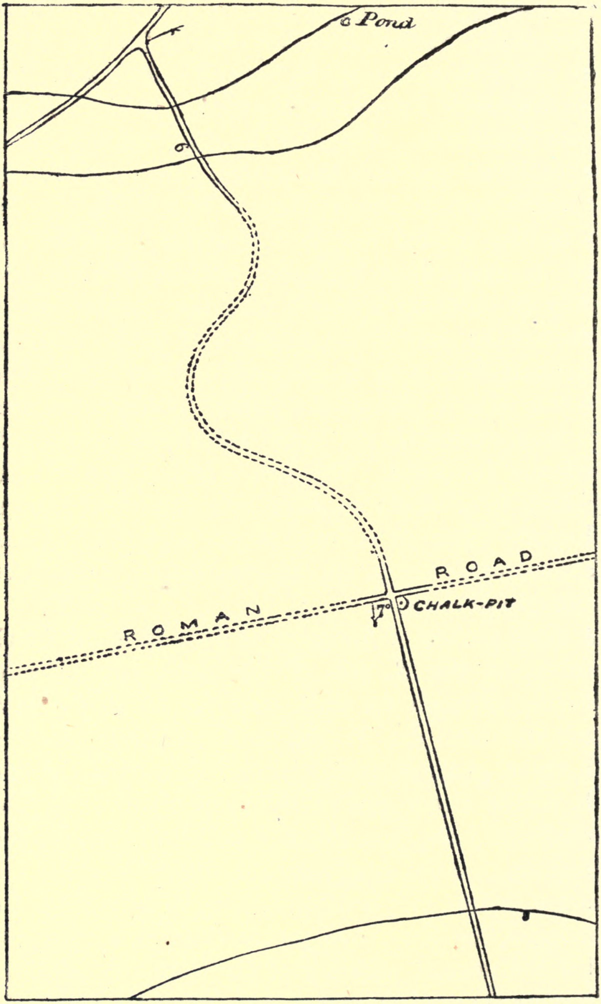


Fig. 7. (Third Slip.)

We have heard that a chalk pit may be seen by the road that crosses our third slip, fig. 7, and we will commence our survey there or thereabouts. On the way and near the S. margin of the map, clear grey sand has been thrown out from a hole newly-dug for a gate-post; this is very different from the sand seen in the first and second slips surveyed, and we conclude, from the level and general run of the country, that it can hardly pass *beneath* the chalk. However, no other good section is obtainable, and there seems no chance of getting at the junction, for the soil is so deep and there are no ditches worthy of the name. We can simply dot in a line where the sandy soil appears to end, and so for the present leave it and get on to the chalk pit.

This is a fine excavation on the very highest point in the map, and to the N. commands a view down and beyond the chalk escarpment, which at once indicates that the mapping of this slip will give but little trouble —chalk, bare chalk in rounded hills and hollow, everywhere is visible. Having made our notes in the pit (Part II.), we descend the road which winds down the steep slope, and has been cut through the higher ridges, frequently exposing the chalk—in the first part with layers of flint, in the lower portion without any flints at all. Here is an exposure of sand, and where the roads meet a small pond in clay—the same kind of thing exactly that was met with in our first and second slips—and on turning up the road to the left we make out a junction of the beds. These are then easily traced to the margin of the map, by feature in the usual way, the lower line running by a pond that is shewn thereon.

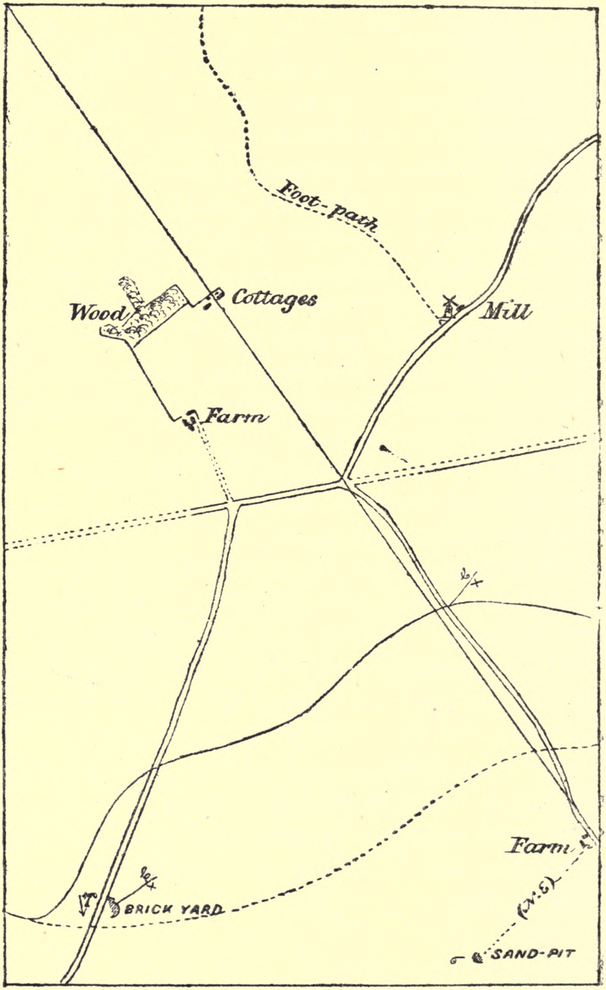


Fig. 8. (Fourth Slip.)

In making another expedition to survey the fourth slip, fig. 8, we enter upon its area, let us suppose, near the top of the chalk escarpment, which is completely overlooked from the road. We pass on by the windmill, not troubling to search for sections as chalk everywhere abounds, turn to the left at the branch roads, and presently observe in a road cutting some mottled loam, yellow, red, and brown. In slip 3 we found grey sand apparently resting on the chalk—this is something very different, and we dig a trench down the side of the cutting to ascertain if the grey sand be here beneath the loam. It is not, but we come upon a bed of dark brown clay enclosing *green-coated* flint pebbles, and below this the chalk itself. We make our notes of these facts (Part II.), find our exact position on the road by a bearing (N.) on the windmill, and draw a line across the road at the boundary. Nothing more worthy of note occurs until we come to a small pit near the corner of the map, dug into clean grey sand similar to that in slip 3. This is put down on the map by aid of a bearing (N.E.) on the farmhouse and pacing the distance therefrom, as no other object is visible on which to take a second line of bearing.

On the other road in the slip is a brick-yard, where the junction of the chalk and overlying mottled loam, including the brown clay with green pebbles, is visible —and we ascertain that sand occurs just to the S. of this spot. From this we conclude that the sand here rests on the loam, and getting occasional hints from the drains and ditches, we draw our lines, and the mapping of slip 4 is completed.

The four slips which we have surveyed form parts of one map, although for the sake of clearness they have been hitherto treated as distinct: on placing them together in proper position they would be found the same, but on a larger scale, as the coloured map in the frontispiece. The former may be considered as one's working or field copies, the latter as completed for reference or for publication.

One slip or one area will frequently elucidate what is somewhat obscure in another; as the Upper Green-sand, mapped in either figure 6 or 7, prove that the sandy soil at the S.E. corner of figure 5 is due to that formation, although in the slip itself no sections were obtainable.

> *Note.*—The process of mapping the older and more disturbed rocks is somewhat different, and is much facilitated by an acquaintance with the methods of observing their inclination and lithological characters. An example of this kind of work will be given, but is deferred until after those methods have been considered in Parts II. and III.

Memoranda.—We have now constructed a geological map on which are shewn (with, let us hope, a reasonable approach to accuracy) the outcrops of four formations—the mottled Loams, the Chalk, the Upper Green-sand, and the Gault. We have proved their relation to each other, and with the data obtained in the pits shall be able to draw therefrom a section also, perhaps several hundred feet in thickness. But, as this will be considered in the second portion of the work, we will now proceed to notice several things which should be borne in mind while mapping geological boundaries.

It frequently happens that lines have to be drawn through large parks, woods, moors, and marshes, where, perhaps, no evidence whatever can be obtained. In these cases the difficulty may be considerably lessened, by first mapping for a good distance all round such obscure areas. With the data and the ideas thereupon thus gained, the lines may then be run by feature alone with every chance of accuracy.

Where there is but little or no change of feature, the line being traced should be kept well up above where it would at first seem to run—for this reason, not only is the *débris* of the upper rock constantly falling upon the outcrop of the lower, but the soil also which properly belongs to it is continually being washed down to a lower level. This for some distance down gives a deceptive indication of the upper rock, where the lower only would be found on making an excavation.

The varying hardness and the dip of the rocks give the form to the district in which they come to the surface. For, precisely in inverse proportion to these conditions, have the agents of denudation worn them away; or, to put the proposition in another form, the prominent minor features of a district are in exact proportion to the power its rocks possess of resisting denudation. As dissimilar rocks thus make a change of feature along their junction, a knowledge of the fact is, as we have seen, of great service in drawing their lines of boundary.

But denudation will also *obscure* the minor features that it has made, for the rain-wash which is the immediate result of sub-aërial erosion will lodge on projections and fill up hollows. The eye will, however, by practice, get accustomed to look and to make allowance for this condition of things, and assign its proper place to the line of division.

Traversing.—In surveying a district of which it is necessary or desirable to map very accurately the outcrop of the strata, the ground must be gone over much more closely than is indicated by the preceding examples. It then is well to follow the lines of ditch and fence by which the area is intersected, as these serve to guide one in traversing all the ground without going twice over any portion. Such lines are, as a rule, somewhat irregular, and occasionally too far apart for the purpose, when they must be left and the intervening

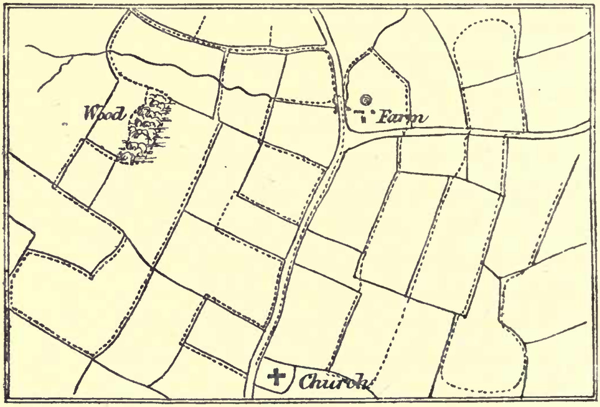


Fig. 9. Showing Two Methods of Traversing Ground.

spaces walked over. The above diagram (fig. 9) shews two very useful methods of traversing ground—one on each side of the main road—the dotted line, starting from the church, traces the path along which the walk is taken. It will be seen that these dotted lines cover the area at about the width of one field apart; if a pond, or the chance of any other section offers, a divergence thereto must be made. By walking over the ground in this way, all the details of the strata, however numerous they may be, are collected as it were at once, and a portion, first of one line, then of another, is drawn, as we cross and re-cross the boundaries. But sometimes it is found more convenient to commence and follow out one line—this is best done by walking along a ditch or fence until we cross the line, then along the bottom of the field to the next fence, up this until the line is again crossed, and so on.

When walking over and geologically mapping any area, it may seem almost impossible to, as it were, convert oneself into a surveying machine—to simply dig out certain physical facts—to put down on paper what one actually sees or discovers, and for the time do nothing more—yet this is the best plan that could be adopted. The occupation itself affords much ground for speculation, as to the extent of this rock, and the thickness of that, the relation of the one to the other, the age of each, and the amount of denudation to which it may have been subjected. This is pleasant amusement enough, and in one sense profitable also, but a geologist thus reasoning in his own mind before he has obtained sufficient data on which to base his ideas is really *theorising;* and it is astonishing to find how readily the facts afterwards ascertained may seem to support a theory thus pre-conceived. The machine-like method of procedure should be as far as possible followed, until a considerable area has been accurately mapped, and all available data obtained and correlated, then a theory, or it may be a generalisation can be based thereon, with a reasonable faith in its soundness and truth.

Symbols.—Three sets of symbols are here appended, and may be found useful, but of course any other letters, figures, or devices, would answer the same purpose. Those in the first column (Greek letters) can be recommended for simplicity and convenience, as the tail possessed by each letter when prolonged, is serviceable in marking the exact spot at which a section is visible.

Limestone	Λ	*L*	□ ⊙
Sandstone. Sand	σ	*s*	·
Gault	Γ	*G*	//
Chalk	Χ	*ch*	||
Thanet beds	τ	*t*	/.
Reading beds	ρ	*r*	|·
London clay	λ	*l*	\\
Boulder clay	β	*B*	╪
Brickearth. Loam	ϵ	*b*	⨪
Gravel	γ	*g*	. ∴
Clay	κ	*cl*	=

Two or more symbols may be so arranged as to indicate at a glance the relative position in which the beds are seen in section, by a line between them indicating the inclination (if any) of the divisional planes of stratification or of a fault. Thus a section of gravel, over Thanet beds faulted against chalk, would be shewn $\frac{\gamma}{\chi \setminus \tau}$ and a bed of Limestone resting on Sandstone, and dipping in the same direction $\frac{\Lambda}{\sigma}$. (*Whitaker.*)

The following table gives the symbols or signs engraved on the published maps of the Government Geological Survey, to indicate the occurrence at the points where they are shewn of certain phenomena that have been ascertained either from actual observation or authentic information.

Stratification.

+	Horizontal
┼	Vertical (longest line on the strike)
×	Undulating
∿	Contorted
↓	Highly inclined } With general dip in the direction of the arrow.
	Undulating }
	Contorted }
↕	Anticlinal axis
✳	Synclinal axis
↙	Dip from observation (with No. of degrees, thus ↙5°)
	Dip from information
	Cleavage
	Limestone quarries

White Lines=Faults at the surface
Yellow „ =Faults underground

Glacial Drift.

⬭	Roches montonnées	
	„ „ striated	Direction of Ice-flow not apparent.
	Flat surface striated	
	Roches montonnées striated	Shewing direction of Ice-flow.
	Flat surface striated	

Ores of the Metals.

☉ Gold	☽ Silver
♀ Copper	♃ Tin
♄ Lead	✳ Manganese
♂ Iron	Zinc

Drift Deposits.—There are certain deposits of gravel and clay to which the methods of mapping previously described are scarcely applicable without additional suggestions for the student's guidance. He will have made himself acquainted theoretically with the phenomena of the "Glacial Period," but the relics thereof which he will come across in his field expeditions are sometimes very puzzling in their nature and relations. The products of the climatic and physical conditions that then prevailed are, generally speaking, a series of clay beds, sometimes contorted—succeeded in places by gravels and sands, as a rule false-bedded and very irregular in their distribution and mode of occurrence; these are in turn overlain by unstratified clay, enclosing fragments of many kinds of older rocks, and known as "Boulder-clay."

These glacial deposits may and do occur singly or together, sometimes one may be absent, sometimes another; but the peculiarity of them all is, not being confined to any definite level, having indeed neither true dip nor horizontality. They spread indiscriminately over an old denuded surface, high and low ground alike, capping the hills and filling the valleys, so that over large areas the underlying older formations are completely hidden—and this perhaps by a sheet of material which, compared with the older formations, is comparatively thin and unimportant. Still the "Drifts," as they in common with more recent deposits are called, may be classified, and no geological map can be considered complete from which they have been omitted.

As these beds, except in rare instances, contain but few, if any, fossils, the frequently scanty items of evidence to be obtained from sections, and the inferences from feature must generally be depended on for determining the order of their super-position. Where no sections shewing junctions are met with, the form of the ground may afford some hints as to which of two beds is the upper, and which the lower, for a gravel overlying clay will not make quite the same kind of feature as it does when passing beneath. Assuming of course that "Drift" of some kind is in question, it will generally be found that a rounded hill consists of clay; if the lower part of its flank be gravel or sand and comparatively steep, such gravel or sand may reasonably be supposed to pass under the clay—but if, on the contrary, it forms a flat or sloping plain, it probably rests upon it. For the lower part of a bed of gravel or sand, protected above by a more tenacious bed of clay, is cut back at a rate disproportionate to that of its upper part, and a more or less abrupt rise is the result. Gravels frequently make flats and sometimes long ridges, cut off as it were from the land at similar heights around them.

The boundary lines of drift must be closely followed, if an accurate map of the beds be desired—contour is of but little use except as a guide to the eye in drawing lines between the points through which they have been found to run, and these points should be at no great distance from each other. A drift clay may be found in one place on the top of a hll, and not on its flank or at its foot, but a few hundred yards away it may perhaps be discovered trailing down the slope, and even crossing the valley, with none on the high ground whatever. This must necessarily be the case, as we see on reflection, for the drifts repose on an irregular surface, and those portions which occupy the old hollows and channels have been able for the longest time to resist erosion. Were it otherwise, we should probably now find the older hills only capped with drift, and the valleys again cleared out by the agents of denudation—but in all rocks hard or soft, old or recent, the anticlinal line is the most readily denuded. Partly, it may be, from the bend having somewhat opened out its particles by tension, thus producing in some cases fractures, and in others weakening its power of resistance. Partly, or it may be entirely, to the inward and downward dip of the beds on each side of an anticline, which would make them relatively stronger than the intervening flat part to resist the attacks of erosion. Another and not unimportant reason may be, that a considerable portion of the rain falling thereon percolates down into the rocks with such inclination and is thrown out elsewhere, while along the axis of elevation it all flows over the rock and removes a proportionately larger share of its material.

It may be well here to remind the student, that in "drifts," the lower as regards level is not necessarily the older of two or more deposits; take, for instance, the gravels occurring in a large drainage area. In past time the river has spread a large sheet of gravel, through which, as denudation went on, its course was again cut with a lowering of its level, perhaps 20 feet. It deposited more gravel, which was in turn cut through and the river's course was again lowered, it may be other 20 feet. In such a case the gravel at the higher level is the older, and the various deposits form terraces at heights 20 feet apart, marking as many stages in the formation of the valley. Such are the higher, lower, and intermediate terraces of gravel in the Thames and other valleys—the higher and older enclosing the remains of extinct animals and of palœolithic man, each succeeding lower terrace more nearly approaching to the existing state of things, and the last deposits having been formed within quite recent periods.

These old valley gravels are now reduced to mere patches in comparison with their former extension, but from their consistency are much more easily mapped than are the glacial drifts—so also are the latest deposits of all, such as brick-earth, gravel, and sand, at about the same level as the rivers. The recent beds are frequently found first on one side, then on the other of existing streams, the present channel running along one edge, then cutting across to follow for a distance the other side, as shown by the stippled area in the frontispiece. The lines of alluvium or marsh-land are as we have seen (p. 23) readily drawn, and it is a good plan in making a geological survey for this deposit to be the first mapped. One thus gets a chance of seeing sections in the lowest beds, and obtains also an idea of the physical geography, or at all events of the valley-system, of the district.

PART II.

SECTIONS.

CHAPTER I.

GEOLOGICAL SECTIONS.

Dip—Strike—Clinometer — To find direction of Dip—To find amount of Dip—Table of Dip, depth and thickness—Exposed Sections—Notes.

Dip.—Strata are but rarely found in an absolutely horizontal position; it is indeed mainly owing to their deviation therefrom that so many formations are now seen outcropping at the surface of the earth. A knowledge of the angle at which they are inclined is of great service to the geologist when drawing horizontal sections to show the beds of a district, and in enabling him to affirm, within reasonable bounds, the thickness of a deposit and the depth at which it will be found in any specified locality. The angle at which a bed deviates from the horizontal is its "angle of dip," generally and for sake of brevity called simply its "dip." A line passing from any point on the surface of a bed through another point which is the lowest possible at that distance from the first—in other words, the line of greatest steepness —represents the dip's direction.

Strike.—Another line, crossing at right angles this line of dip, that is of greatest steepness, must necessarily be horizontal—it would therefore coincide with the edge of a bed that might come to the surface in a perfectly level tract of country. This seldom occurs, and owing to the general unevenness of the surface an outcrop can rarely be represented by a straight line, although the dip may for a long distance continue the same. But a line through all points, situated at the *same level* on a boundary, will always be found to lie at right angles to the "dip;" this line is called the "line of strike," or shortly "strike," of a bed or a formation.

From a consideration of the above, it will be seen that as the "direction of dip" varies, so also will the "line of strike," which is roughly the outcrop of a formation:—inversely, as the "line of strike" or outcrop varies, so also will the "direction of dip" in equal proportion. Of this we may at all times be certain, even although no ocular evidence be forthcoming, and the fact will frequently be found to aid us in our geological investigations.

It is a self-evident proposition, that as the amount of "dip" varies, so does the horizontal breadth that the outcrop of a bed of constant thickness will occupy at the surface. But it is a very useful thing to remember in geological surveying, also in drawing sections where the evidence is scanty, especially as for the latter purpose the actual slope of the ground is ascertained. It follows, that the value of any two of the three factors tabulated below being known, that of the third can easily be ascertained.

1. The thickness of a formation.

2. The dip.
3. The horizontal breadth of outcrop.

Clinometer.—It matters little by what kind of instrument the dip of strata is ascertained, so long as it indicates with a fair approach to accuracy the amount of inclination. All clinometers must possess a graduated arc, and either a pendant that hanging perpendicularly, or a spirit-level lying horizontally, shall show the number of degrees that its base deviates to either hand from a horizontal plane. A simple form of clinometer

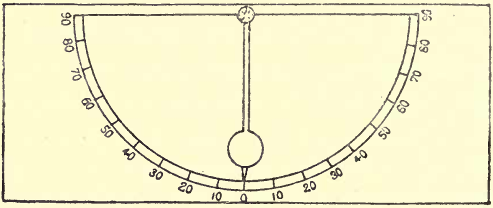


Fig. 10.

is shown in fig. 10; but as portability is a great desideratum, and as the pocket compass, which should be the geologist's constant companion, possesses a graduated circle, the one instrument may well be made to answer the two purposes. This is effected by the addition of the parts shown by the dotted lines in fig. 1, and of a small pendant swung from the point which carries also the magnetic needle. When the two instruments are thus combined, the circumference must be divided not only into cardinal and intermediate points, but also into degrees numbered to the right and left of zero. This point is just over the centre of the clinometer base, the figures run up to 90° on either side, and then back to zero at the top, so that the instrument can be used inverted, and placed to the under-side of a bed if required.

To take the dip of a bed in a pit, quarry, or elsewhere, clear away the material from its upper surface in a part as flat as can be found, and which follows as nearly as the eye can detect the general line of the whole mass exposed. Place the clinometer on this, or what is a better plan, on a stick, or hammer-handle, first laid on the rock; this being of greater length than the instrument is less liable to error from an undulating surface. See that the clinometer is directed along the steepest part of the cleared surface, which is probably *not* in a line with the face of the pit—also that the pendant is swinging freely at the time; when it comes to rest, read off the number of degrees and make a note of the result. In some cases, as beneath a ledge of rock, in a mine, or in a cavern, it is more convenient to take the dip from the under-surface of a bed, when, by the upper edge of an ordinary clinometer, or by the inversion of the compass-form of instrument, the same result may be obtained. In other cases neither the upper- nor under-surface of a bed can be got at without much labour, when the hammer-handle or stick should be held along the exposed face, as nearly as may be in the line of the bed, and the clinometer placed thereon. Again, beds may be exposed in cliffs or deep pits, at such a height or in such a position as to be not readily accessible; under these circumstances, the observer should take his stand at a good distance from the face of the cliff or quarry, at right angles, or thereabouts, to the spot where he wishes the dip to be determined. Holding the instrument steadily before his eye, he inclines it until its edge coincides with the bed being observed, and then reads off as quickly as possible the angle indicated, and before the position of the clinometer is shifted; to ensure accuracy by this method, two or more observations should be made and the results compared.

In the two last-named instances—the exposed face, accessible and inaccessible—the *apparent dip* is taken; this may or may not be the *true dip,* which can be greater, but cannot be less than that of the exposure. Wherever possible, and unless the observer be certain that he is getting the true dip, he should make two observations, the direction of one at a considerable angle from that of the other, and work out the true dip by one of the methods given in the following pages.

The final results of observations taken with the clinometer—the amount and direction of the dip (if any) of a bed or formation—are shown on the map by the symbols given in the table at page 33, drawn in vacant spaces as near as possible to the spot where the sections are exposed.

To find direction of Dip, by diagram.—When the amount and direction of two lines of apparent dip are known, the direction of the true dip may readily be found by one of the following Rules, A or B.

RULE A.—When *both* the observed dips incline from or towards the angle enclosed by their lines, fig. 11, the true dip is at right angles to a line (*a b*) laid down by the following method:

Set off from the angle on each of the two lines of apparent dip a number of units corresponding to the number of degrees of dip observed along the *other* line, and connect the two points by a line *a b*.

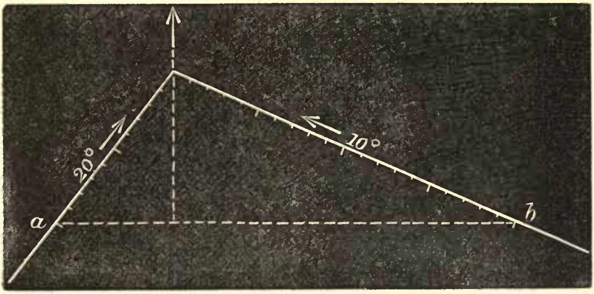


Fig. 11.

(This line coincides with the strike, and is consequently at right angles to the true dip's direction.)

Rule B.—When one observed dip inclines from, and

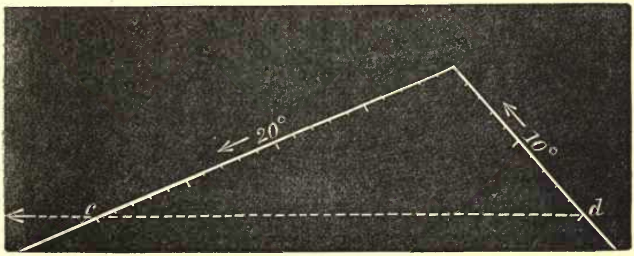


Fig. 12.

the other towards the angle enclosed by their lines, fig. 12, the true dip follows a line (*c d*) laid down by the following method:

Set off from the angle on each of the two lines of apparent dip a number of units corresponding to the number of degrees of dip observed along that line, and connect the two points by a line *c d*.

(This line coincides with the true dip's direction.)

Note.—These rules will not apply, unaltered, to lines of apparent dip, enclosing *acute* angles which in practice are rarely found, but to right angles and all beyond they are applicable. In such cases, a horizontal triangle constructed by the reverse rule, *i.e.*, on the *opposite* side of either line of observed dip, will give the result required. (See the N.E. corner of quarry, fig. 14, as an illustration.)

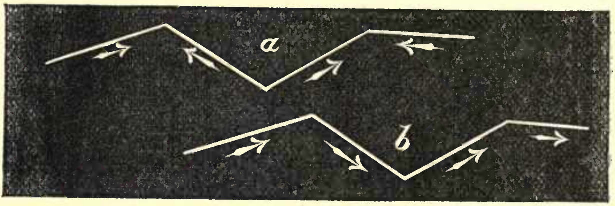


Fig. 13.

From the preceding two rules a general one may be drawn, and which as an aid to memory of the others may be of service. When the apparent dips cross each other, as in *a* (fig. 13), the dip *crosses* the line which will be drawn by Rule A. When all run in the same direction, *b*, the dip *coincides* with the line drawn by Rule B.

Note.—When any part of the section-face shows the beds in a horizontal position, the true dip (if any) is of course at right angles thereto, and no further trouble need be taken.

The quarry represented in fig. 14 may be taken as an example of obtaining the true dip by these methods, the operation being repeated, and in each case with the same result.

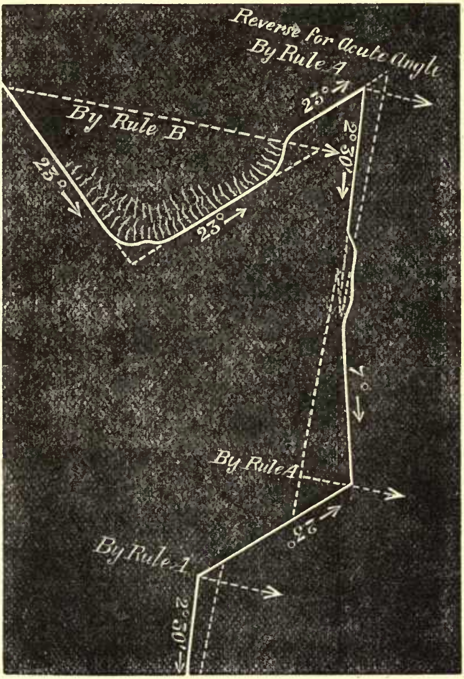


Fig. 14.

To find amount of Dip, by diagram.—For examples of this, the cases in which the direction of dip was

NOTE.—The foregoing Rules were first published by the Author in a communication to the "Geological Magazine" for May, 1876 (p. 236). Mr. O. Fisher, after a careful examination of the methods suggested, wrote to say that "Rule A is correct for small dips for all practical purposes. It is not necessary that the angle between the faces of the quarry should be obtuse. The rule is equally true whatever be the angle. But Rule B, I am afraid, is not correct. I should suggest the following mode of applying the rule in case B."

found by Rules A and B may be taken — figs. 11 and 12.

Construct (fig. 15) a right-angled triangle, which shall

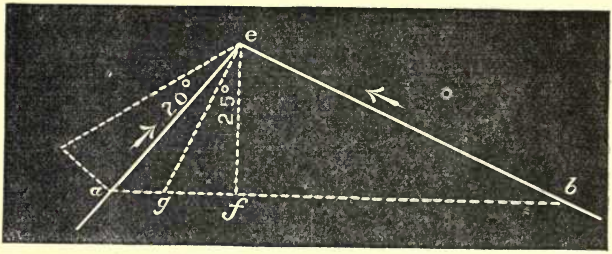
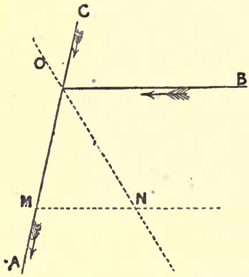


Fig. 15.

represent the apparent dip on the part of an exposed



"Draw from any point M in the quarry, M N parallel to the face O B, and set off M N so that dip in O B : dip in O A : : O M : M N. Then O N is the direction of the *strike*."

In the "Geol. Magazine" for June, 1876, Mr. H. G. Day suggests, "In the first rule (A), instead of 'the number of degrees of dip,' write 'the tangent of the angle of apparent dip.' In the second rule (B), proceed as before, but measure the length along one of the lines produced backwards."

There is a slight error arising from the difference between the circular measure of the angle and the tangent of that angle—but in most cases it may be disregarded. And instead of adopting Rule B when "one observed dip inclines from, and the other towards the angle enclosed by their lines," it will be well to work out the dip from a horizontal triangle constructed on the other side of one of the lines. Both apparent dips will then run either from or towards the angle, and Rule A can be applied; as, for instance, B O C in the figure, instead of B O A, the angle of the quarry.

face, where it has been observed (in this case 20°), and the direction of true dip found, by Rule A. Let the face-line itself form the base (*a—e*, fig. 15, or *c—e*, fig. 16) of the triangle, thus saving trouble, and making the method, perhaps, more readily understood. It is found that in the distance *a—e* (or *c—e*, fig. 16) the bed rises a certain number of feet or inches, but along the line of true dip, *e—f* (or *c—d*, fig. 16), it of course rises the same number of feet or inches. Set off this amount of rise then at right angles to the true dip—as in the other case it is at right angles to the apparent dip—and draw a line from the point *g*, thus marked off, to the point *e* (or *c*, fig. 16), where the rise commences, the angle enclosed (25°, fig. 15, and 21°, fig. 16) is the measure of the true dip. It must necessarily be

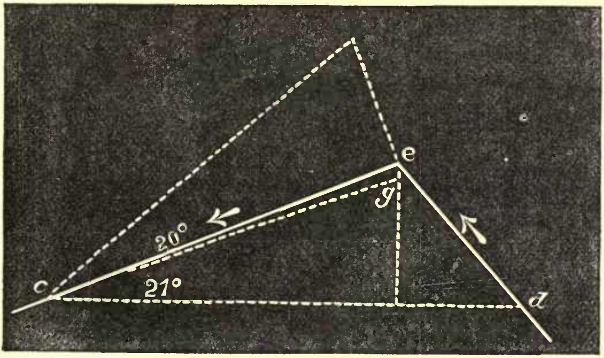


Fig. 16.

a greater angle than that of the apparent dips observed, because the bed rises to the same height in a shorter distance.

The same method applies whether the line of true dip has been found by Rule A or B, and the angle re-

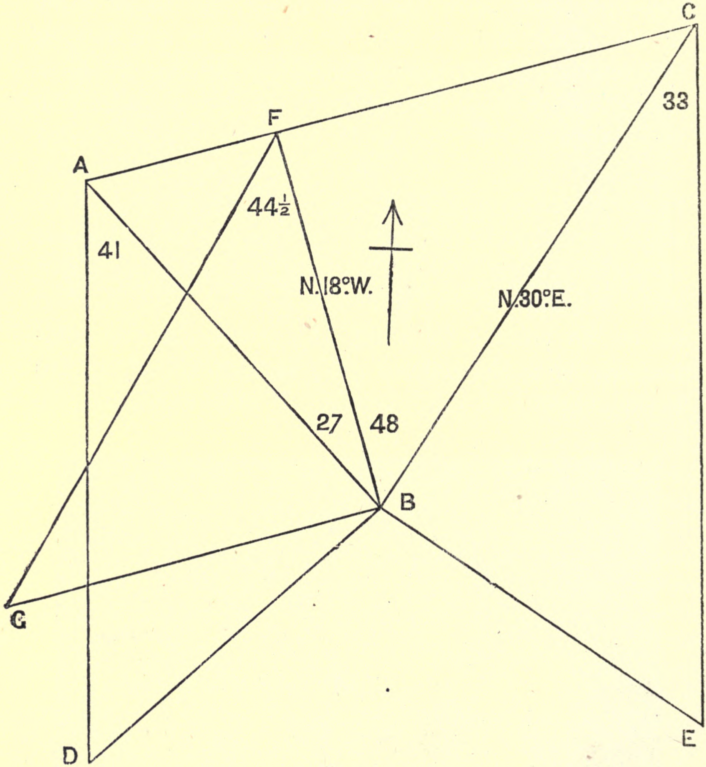


Fig. 17.*

quired can be found from either of the apparent dips, or it can be worked out from both as a check upon the result.

* For the loan of this woodcut, and another (fig. 20), the author is indebted to the Editors of the "Geological Magazine."

The following method of finding by diagram, "from two apparent dips the full dip and its direction," was published by Mr. W. H. Dalton, of H.M. Geol. Survey, in the "Geological Magazine."*

Problem.—From two apparent dips to find the full dip and its direction (fig. 17).

Suppose two apparent dips, 41° N.W. and 33° N. 30° E.

Result, 44½° N. 18° W.

Draw B A, B C in the directions of the apparent dips; erect B D, B E vertical to B A, B C respectively, and equal to each other. From D, E, draw D A, E C, making B A D, B C E equal to the apparent angles whose direction is shown by B A, B C respectively. Join A C, and draw B F vertical to it. Draw B G parallel to A C, and equal to B E; join F G.

Then B F is the direction of the full dip, and G F B its amount.

Proof.—If A B C be placed horizontally and A B D, B C E, B F G vertically, D G and E will coincide, and D A, G F, E C and A C will be in the plane of stratification, giving the apparent angles at A and C and the full dip at F. In practice, the triangle B G F might be more expeditiously constructed between B F and A C.

From any two observed dips the amount and direction of the true dip may be ascertained by calculation; but for all practical purposes the results obtained by diagram are sufficiently accurate and much more expeditious.

* Vol. x., No. 7, p. 332.

TABLE OF DIP, DEPTH, AND THICKNESS.

Proportionate Incline.	Yards of Rise or Fall in 1 mile.	Amount of Dip. Degrees.	Depth from Surface. Distance=100	Thickness of Beds at right angles.
1 in 57·	30	1°	1·75	1·75
1 in 29·	60	2°	3·45	3·45
1 in 19·	90	3°	5·25	5·25
1 in 15·	118	4°	6·75	6·75
1 in 12·	147	5°	8·75	8·75
1 in 10·	176	6°	10·5	10·5
1 in 8·5	208	7°	12·5	12·25
1 in 7·3	240	8°	14·5	14·25
1 in 6·5	270	9°	16·5	16·25
1 in 5·8	300	10°	17·75	17·5
1 in 5·25	333	11°	19·75	19·25
1 in 5·	365	12°	21·25	20·75
1 in 4·5	397	13°	23·25	22·5
1 in 4·	430	14°	25·	24·25
1 in 3·8	463	15°	26·75	26·
1 in 3·5	495	16°	28·5	27·75
1 in 3·3	528	17°	30·	29·25
1 in 3·1	560	18°	32·3	31·3
1 in 3·	594	19°	33·5	32·5
1 in 2·8	630	20°	35·7	34·25
1 in 2·6	665	21°	38·25	36·0
1 in 2·5	700	22°	40·	37·75
1 in 2·4	735	23°	41·7	39·5
1 in 2·3	770	24°	43·5	41·
1 in 2·2	805	25°	45·5	42·25
1 in 2·1	842	26°	48·	43·75
1 in 2·	880	27°	50·	45·25
1 in 1·9	925	28°	52·5	47·
1 in 1·8	970	29°	55·5	48·25

TABLE OF DIP, DEPTH, AND THICKNESS—*continued.*

Proportionate Incline.	Yards of Rise or Fall in 1 mile.	Amount of Dip. Degrees.	Depth from Surface. Distance=100.	Thickness of Beds at right angles.
1 in 1·7	1015	30°	59·	50·
1 in 1·65	1060	31°	60·6	51·25
1 in 1·6	1105	32°	62·	52·75
1 in 1·54	1150	33°	65·	54·25
1 in 1·48	1195	34°	67·5	56·
1 in 1·43	1240	35°	70·	57·5
1 in 1·37	1285	36°	73·	58·75
1 in 1·33	1335	37°	75·2	60·
1 in 1·28	1385	38°	78·	61·25
1 in 1·22	1435	39°	81·6	62·75
1 in 1·18	1490	40°	84·8	64·5
1 in 1·	1760	45°	100·	71·
	2095	50°	119·	77·
	2515	55°	143·	82·
1 in ·67=$\frac{2}{3}$	2640	56°	150·	83·
	3060	60°	174·	86·5
1 in ·5=$\frac{1}{2}$	3520	63°	200·	89·
	3765	65°	214·	90·5
	4840	70°	275·	94·
1 in ·33=$\frac{1}{3}$	5280	71°	300·	94·5
	6475	75°	368·	96·5
1 in ·25=$\frac{1}{4}$	7040	76°	400·	97·
1 in ·20=$\frac{1}{5}$	8800	79°	500·	98·
	10120	80°	575·	98·5
1 in ·1=$\frac{1}{10}$	17600	84°	1000·	99·5
	20115	85°	1140·	100·

Note.—Messrs. Troughton and Simms, of Fleet Street, London, prepared (at the suggestion of the late Mr. Jukes) a little ivory protractor (p. 9) on which portions of similar Tables to the above are engraved, together with the scales of the six-inch and one-inch maps, and which the observer will find very useful to have in his note-book or map-case. Its price is 10*s*.

The foregoing table has been prepared for the purpose of getting an approximate idea of the rise or fall of the ground in a certain distance, or of the depth to which a bed with ascertained dip may have descended at any particular spot, and the consequent thickness of the beds above it. The centre column gives the angle of inclination of the beds or of the surface, the columns on the left hand the proportion of rise or fall, as the case may be; those on the right the vertical depth to a bed at 100 units from its outcrop, and the actual thickness of the beds above, supposing them to have been in their original plane of stratification. These 100 units are measured along a *horizontal* surface in the direction of its dip, and allowance has of course to be made for rise or fall of the ground, if uneven between the points.

Exposed Sections.—In the examination of the rocks exposed in quarries, pits, and so on, we make a definite series of observations. On entering we should probably have in our mind a general idea of what we are going to see (except in a district quite new to us), from former experience of the rocks in the neighbourhood, or from what might otherwise be reasonably expected. We should also infer from the kind of excavation in what material it had been made—as, for instance, a brick-yard, which would be in clay or loam of some kind; a lime-kiln in limestone, whether of compact nature as the "Lias," or earthy as the "Chalk." In a glance round the excavation we get further ideas of the general character and lie of the beds, and we then proceed to make more detailed examination.

Note.—Railway cuttings often afford excellent means of observing the strata; although perhaps not of great depth, their length is sufficient to bring on, it may be, several beds that are slightly out of horizontal position, and to show them in their actual superposition.

The points of which special notes have to be made are, the kind of rock of which the bed or series of beds consists; the number, thickness, and sequence of those beds, their apparent dip and its bearing; also the true dip if it can be obtained. All peculiarities must be sought out and noted, such as false- or current-bedding, cleavage, concretions, signs of fracture, slickensides, and so on—the lines of bedding and jointing observed, and, in short, anything and everything that can be detected and described. (The modes of determining the nature of the rocks are described in Part III.; and of finding, collecting, and preserving the included fossils, in Part IV.)

Notes.—As illustrations of the manner in which pit sections are observed and noted, we may select those that occur in the area supposed to have been surveyed, and which is represented in figs. 5, 6, 7, and 8. In the first slip, fig. 5, soon after starting, we came upon an old pit, nearly overgrown, but of which some notes must be taken.

(*a.*) In the lowest part of this pit we find, after removal of the fallen soil, a fair section of fine light sand, with many green-looking grains scattered amongst its other component particles. Some lines of bedding can just be made out, and these appear to be horizontal or nearly so, but they are not defined sufficiently for a dip to be taken from them, and in one place a thin broken-up seam of harder sand, almost a stone, occurs. Some elongated lumps of whitish material are imbedded in the harder sand, and which, on being broken across, present a sponge-like appearance. These evidently are, or were, organisms of some kind, and are transferred to the fossil bag for future investigation.

The top part of the S. side of the pit is in soft marly chalk, and as we dig down the slope this chalk gets darker in colour, owing, it would seem, to the number of green grains enclosed in it. Presently we come down to the grey sand with green grains, but without having noticed any sudden change where the one rock rests upon the other. There is in fact a gradual passage from the chalk into the sand, representing an equally gradual change in the conditions of deposit. Still there is clean chalk above, and clean sand below, therefore this passage portion represents the junction, and the line is consequently drawn through that part of the map where the pit is situated. These observations may be noted in the following manner:—

Date . . . . 187 .

(Old) Sand-pit ½ furlong N. of ——— church.

(About) 10 feet, fine light-coloured sand, with *green grains*, apparently horizontal, including a thin seam of broken sandstone (with ? sponges).

Chalk marl, with green grains, comes on at the S. side, and passes down into the sand.

FOSSILS (determined in Part IV. Chap. iii.).

Upper Green-sand. {
Terebratula
Rhynconella
Ostrea
Plicatula
Ammonites

Chalk-marl. { *Terebratula*
Inoceramus
Belemnites }

(*b.*) The brick-yard beyond the stream (fig. 5) was found to be situated on a clay; this on examination proves to be Gault. It is a tenacious clay, in colour dark blue where freshly cut, but weathering to a light grey on exposure. No traces of bedding are visible, unless a thin horizontal layer of rounded grey nodules which occurs in one part, and is tolerably persistent throughout the pit, affords such indication.

Date . . . . 187 .

Brick-yard ½ mile N. of ——— church.

17 feet, dark blue tenacious clay (weathers grey), ? horizontal—about 7 feet from bottom 1 layer of phosphatic nodules, shells, and casts.

FOSSILS.

Gault. {
Ammonites varicosus—splendens—rostratus
Hamites
Belemnites attenuatus
Rostellaria
Solarium ornatum
Plicatula pectenoides
Avicula gryphœoides
Inoceramus sulcatus
Nucula pectinata
Pentacrinus Fittoni }

(*c.*) Date . . . . 187 .

New Well $\frac{1}{2}$ mile S.E. of ——— church.

(Information obtained from the well-sinker.)

Gault.	107 feet, dark blue Gault, with some seams of nodules.
	1 foot hard bed
Lower Green-sand	2 feet running sand
	110 feet=Dug 50 feet, bored 60 feet.

Water stands 30 feet from surface.

(*d.*) No pit sections occurred in the second slip, but in the third was a large chalk-pit, just on the highest point of the escarpment. Here we see that a great deal of the rock is being daily removed, most of it converted into lime at the kiln within the pit, some portions carted away for road-making, others for building purposes. The vertical face of this chalk section presents a pleasing picture, and is in itself quite a study; it would afford ample materials for a geological lecture. The rock itself, of snowy whiteness, made up apparently, but only to the naked eye, of minute grains of inorganic dust; the even bands of flint nodules, which, being broken across in the quarrying, look like black lines ruled across the chalk; the "slicken-sided" joints and the little faults and fractures which here and there occur. Above are two funnel-shaped masses of sandy gravel, running down several feet into the chalk; lower down a circular patch quite surrounded by it. This latter proves to be only an offshoot from one of the others, but which having deviated from the perpendicular has been cut directly across. These are "pipes" of gravel, filling hollows in the chalk that have been made by rain-water holding in solution carbonic acid, and which, percolating through into a fissure, has increased the size of its passage by removal, as a bi-carbonate, of a portion of the rock. At some former time the surface must have been covered with a gravel; these are its only relics here, the bulk of the deposit having been removed by subsequent denudation.

We are informed that the pit is forty feet deep, and we approximately verify the statement by counting the spaces between the layers of flint, which are, as nearly as may be, six feet apart; also that the lower part of the chalk in the pit is that which is used for building. On examination this proves to be somewhat harder than the other portions, and it breaks up into larger blocks; but, with the exception of a slightly yellow tinge that it possesses, it is just the same in appearance. Specimens of each kind are chipped out, to be taken away with us, that they may be submitted to test and experiment.

The next proceeding is to select a suitable part of one of the flint layers (in this case on the E. side of the pit), to place our hammer-handle thereon in the same line, and on this again the clinometer—the angle of dip reads 3°, somewhere in a S. direction. Then we try to get another observation at right angles, or nearly so, to the first—at the N. end without success, but on the S. we are enabled to do so by removing some fallen rubbish. This reads 0°, consequently the first observation has given us the true dip of the beds, and the E. side of the pit happens to have been cut in its direction. We take this direction by compass-bearing, it proves to be S. 7° E., and we draw on the map, and near the position of the pit, an arrow pointing S. 7° E., with the number of degrees of dip also shewn (p. 33).

We observe that the chalk is jointed in every direction, and that the surfaces of some of the joints, diagonal and vertical, are of a dirty yellow colour, and covered with small striæ, as though one face of the jointed rock had slipped over the opposing face, both getting smoothed and striated in the process. This is what has happened, the resulting appearance being known as "slickenside" —the chalk has been at some period subjected to slight disturbance—this is further evidenced by the small fractures and faults. In the S.E. corner one of the latter is plainly shewn on a small scale, the downthrow not exceeding 1 foot—the continuity of the lines of flint being broken, all of them suddenly rising to that extent.

All the flints are black but have a thin white coating —the majority occur in nodules of varying size, from that of a hen's egg to a quartern loaf, but one seam is tabular, that is, it consists of an almost continuous stratum of flint about 1½ inches in thickness. Similar flint in tabular form occasionally is seen running away from this seam down the diagonal or vertical joints, and sometimes even cutting directly across a layer of flint nodules.

Date . . . . 187 .

Chalk pit (and lime-kiln) mile of ——
(at junction of the road with old Roman way).

40 feet chalk *with flints* in layers about 6 feet apart—dipping 3° to S. 7° E.—slightly faulted and broken up into blocks of small size. One layer of flint, near the bottom, tabular and running off into the joints, which

are occasionally slicken-sided. The lowest part of the chalk is harder, in large blocks, and of a yellowish tint (used for building).

Pipes of a ferruginous sandy gravel at the top.

FOSSILS.

Ananchytes
Micraster
Cidaris (*spines*)
Belemnites
Inoceramus
Spondylus
Magas pumila
Terebratula carnea
Terebratulina striata
Rhynconella octoplicata
Marsupites Mulleri
Crania
Plicatula
Thecidium Wetherellii
Serpula
Polyzoa

The sections observed during the survey of the fourth slip are given below as noted in the book at the time, no additional remarks being considered necessary.

Date . . . . 187 .

(*e.*) Road cutting ½ mile S. of —— Windmill.
Loam, mottled, yellow, red and brown.
(*thin bed*) Dark clay, with green-coated flint pebbles.
Chalk.

No measurements of thickness obtainable.

(Memo :* This loam is evidently a lenticular mass between the chalk and the grey sand which come together a short distance off to the W. (see p. 27), and probably to the E. also. See map, and notes farther on.

* Made at a later date.

Date . . . . 187 .

(*f.*) Brick-yard $\frac{3}{4}$ mile S. of junction with the Roman road.

13 feet Loam, mottled, yellow red and brown (similar to that seen in road cutting about 2 miles E.) with intercalated patches of white and yellow sand; passing down into

1 foot, dark brown very tenacious Clay, which encloses many angular and rolled flints with green-coating, and rests on an uneven surface of (exposed about 9 feet) Chalk with flints, in layers 5 or 6 feet apart, and dipping 3° to S. 7° E.

Grey sand occurs just S. of this pit (p. 27) and overlies the loam.

Fossils (*from the mottled loam*).

Ostrea

Cyrena cordata

Ostrea bellovacina (*in basement bed*).

(*g.*) Sand pit (small) near S.E. corner of the sheet. About 4 feet (not bottomed). Pale grey sand, very clean and evidently dug for purposes of building, rather darker in the lower portion. (There is a pond close by which probably indicates a change at no great depth to a deposit of loam or clay.)

CHAPTER II.

HORIZONTAL SECTIONS.

Datum-level—Bench-marks—Levelling, *by Aneroid, by Level*—Level-book—Plotting, *from heights*—Levelling, *by Theodolite*—Level-book—Plotting, *from angles*—Filling in Geology—Apparent dip.

In constructing a geological section it is most important to have the surface of the ground along the line of such section accurately represented; for if not, error is sure to creep in, where perhaps least expected, as might easily happen in such an instance as this. A road runs along the line of a proposed section—at one part A, a pit by the roadside exposes a limestone 1 foot thick, with shale above and below; by the clinometer it is found that this bed is perfectly horizontal. The road appears to the eye to be horizontal also, but in reality it rises at the slight angle of half a degree. A mile farther on another pit, similar to the first, shews a limestone 1 foot thick, with shales above and below, just the same as at A, also horizontal. The beds seen in the two pits are surely identical, at least it seems natural to come to that conclusion; but in reality the bed seen at A is here at B, owing to the slight rise, actually from 40 to 50 feet beneath the surface. It might even happen that the higher of two beds would be shewn passing under the other were the surface judged merely by the eye; therefore, if error is to be avoided, the section must be drawn from ascertained data or by the aid of some instrument.

There are many means by which a line can be drawn that shall represent the surface through any number of given points—by some approximately and in a sketchy manner, by others every detail is shewn with the greatest accuracy. Among the former are the methods employed in drawing section lines from the published "heights above the sea," from contour maps, and from heights taken by aneroid barometer; the latter, from levels ascertained by the Y, the dumpy or any other level, and from a series of vertical angles observed by means of the theodolite. All proceed on the same principle of ascertaining the heights at various points, near to or distant from each other, according to the degree of accuracy required, and sketching in the line between those points to correspond as nearly as may be with the surface form of the ground. A few brief remarks will follow on the use of the level and theodolite, for geological purposes. Before the levels for a geological section are run, the beds have generally been mapped, and the line should be laid out as nearly as can be conveniently arranged at right angles to the strike. For approximate levelling the distances apart of the points where heights are taken can be scaled from the map; for accurate work, measurements by chain are required.

Datum-level.—By whatever means the heights or levels for a section are taken, it is necessary to have a fixed or standard level to commence from, to which reference can at any time be made, and in regard to which all the other heights are calculated. It is usual, as it is most convenient, to refer all *heights* to the standard, or as it is called, the "datum-level" adopted for this country, that is, the "level of the sea." By this term is understood the level of mean tide at Liverpool, a datum from which all the heights marked on the ordnance maps have been calculated. But in some instances it is found more convenient to work from an imaginary horizontal line, as datum, so many feet above or below this standard; in others, to take a fixed point on some permanent structure, as a church, or a bridge, and to commence therefrom an imaginary datum. In geological sections, which frequently shew the strata far beneath the sea-level, it is usual, as in those published by the Government Survey, to assume a datum, "1000 feet below the level of the sea."

Bench marks.—Here and there along a line of section, or elsewhere, a series of intermediate points are selected, as "bench marks," for the sake of more convenient local reference at any future time. The heights of these points above or below datum are known from the ordnance levelling, from our own observations, or otherwise, and their positions are indicated or described. All the points on the ordnance maps, where heights are figured, are so many bench marks, the levels of each having been carefully ascertained, and the result checked by repetition and calculation.

It is not always necessary, nor is it always possible, to obtain a B. M. of known height above the sea, from which to commence a proposed line of geological section; in such cases a fixed local starting-point must be selected. If near home, as good a B. M. as any is the step of one's front door, and for aneroid observations, perhaps frequently taken for other purposes than a continuous section, none could be better. While running a section line, started from a local B. M., we may possibly come across one of the ordnance heights; this will enable us, if desired, to reduce our results to "sea-level," even from the commencement.

Levelling.

By Aneroid.—The possibility of taking heights by this instrument is, of course, based on the weight, generally termed pressure, of the atmosphere, which varies as the height above the surface of the earth. But this pressure is subject to almost constant change, at the same place, and at the same height, owing to varying atmospheric conditions of wind, moisture, and so on. Therefore some means must be adopted, when levelling by the aneroid, to compensate for any change that may occur during the time of making the observations, and by which cause, in addition to the difference of height, the needle would be deflected.

The circumference of the aneroid barometer is graduated to inches and hundredths, and on this scale the needle indicates the varying measure of a column of mercury, that would be sustained or counter-balanced by the changing weight of the atmosphere. Generally it has also a movable circumference, divided into parts, about 950 of which correspond with 1 inch on the pressure scale; because a column of air, about 950 feet high, is equal in weight to a similar column of mercury, which measures 1 inch in height. Therefore, as the mercury in an ordinary barometer would fall 1 inch for every 950 feet higher, or rise for 950 feet lower, the needle of an aneroid gives equivalent indications on this outer circumference, which thus saves the labour of calculation.

At starting, the zero point of the circumference must be brought round to a position exactly opposite the point of the needle, the observer standing at the time on the selected bench mark; the instrument should have been previously carried about the person for a few minutes, so that the difference of temperature may take effect, if at all, before and not after this adjustment.

On arrival at each point where an observation should be made, as the summit of a hill, the bottom of a valley, the site of an exposed section, and so on, note is made of the variation of the needle-point—as a rise or fall of pressure, if the instrument is graduated for pressure only; as so many feet higher or lower, if also for elevation. The indicator is not to be shifted at each station, but the height of every one taken as so much above or below the B. M. chosen for a starting-point—as stated before, these heights will not be correct if the atmospheric pressure has changed in the meantime. Three methods are given for the rectification of error arising from this cause; *a* and *b*, being of the simpler kind, will give fair results; should greater accuracy be required, *c* must be adopted.

(*a*.) If the observer can return home along the route by which he came out, and has the time at command for making a second series of observations at each point, the error arising from atmospheric change may be to some extent eliminated. The indicator must remain in the same position as at starting, and the heights on returning be again taken in reference to the primary bench mark. For example, suppose four points on a line, at which the two series of observations are as given below (the sign + indicating that the instrument registers so many feet *above* the starting-point, when *below* the sign — being prefixed).

	B.M.	1st ⊙ (station)	2nd ⊙	Last ⊙
1st series . .	o	+ 200	+ 80	+ 100
2nd series . .	+30	+ 225	+ 100	+ 100

The barometer has evidently fallen during the time through a space equal to 30 feet, making the B. M. appear to be 30 feet higher than at starting, and, as a matter of course, the other stations too high also in due proportion. We assume that the fall was gradual, and equally distributed over every portion of the two journeys; therefore half 30 feet (*i.e.* 15 feet) must be deducted from the *mean* of the two observations at each place, the result gives the required elevation.

	B.M.	1st ⊙	2nd ⊙	Last ⊙
	o	+ 200	+ 80	+ 100
	+ 30	+ 225	+ 100	+ 100
	½/ 30	½/ 425	½/ 180	½/ 200
Mean of two observations	15	212·5	90	100
Deduct error	15	15·	15	15
Elevation	0	197·5	75	85

(*b.*) A somewhat similar method is to note the *time* of starting (with the indicator at zero), and of making each observation; then, on again reaching the home B. M., without having gone more than once to each station, to observe the time, and the rise or fall of the barometer. This rise or fall must be distributed, in proportion to the time that elapsed before each was taken, over the station heights, as additions to, or deductions from, the registered elevation.

It will be seen that the foregoing methods *a* and *b* are founded upon the assumption, that the atmospheric rise or fall of the barometer has been consistent throughout the time occupied in making the observations; but this probably has not been the case, for the pressure may be increasing at one part of the day, and steady or falling at another. The following method (*c*) is free from this defect, and the accuracy of its results depends solely on the perfection of the instruments employed.

(*c*.) An assistant and two aneroids are required by this method, the instruments of sufficient accuracy for no perceptible difference between their indications to arise under varying pressure. The readings are taken at each station at some definite time, such as at the hour, half-hour, or quarter; and the assistant, at home or wherever the starting-point may have been, observes and records the reading of the second instrument at the same intervals. The two sets of observations are afterwards compared, and those taken at the stations corrected for variations, if any, of the atmospheric pressure.

By Level.—The principle on which all levels are constructed is that of a perfectly horizontal visual line intersecting a graduated vertical staff, the difference of readings in two observations corresponding to the difference in level of the two places. If the height of one of these be known, that of the other is readily ascertained in relation thereto, and is called a "reduced level." The difference between the heights of any number of places may be thus determined, and the level taken at each "reduced," by addition or subtraction, to its height above or below the B. M.—the height of this being known, the levels are at once reduced to "datum-level."

The level consists of a telescope supported on three legs, and having a fine cross-wire placed horizontally in the line of sight. A spirit-level is fixed on it parallel to its axis, by means of which, and three (or four) plate screws, the telescope can be adjusted so as to be perfectly horizontal in whatever direction it may be turned. The line of sight thus represents a horizontal plane, and the cross-wire must necessarily, within certain limits, be seen to intersect a distant object in the same plane with itself. The observations are taken by means of a staff placed on the stations in turn—this staff is capable of being extended to 14 feet in height and has one side divided into feet and hundredths. Through the telescope with the ordinary eye-piece it is seen inverted, but the eye soon gets accustomed to reading it in this position; and being magnified the point cut by the cross-wire can be accurately read off.

The distances apart of the various stations can be measured by chain, or scaled from the map on which the line of section has been laid down—the correctness of the height at each station is not affected by want of accuracy in this respect, as it is when taken by the theodolite. The instrument should always be placed about mid-way between the two places at which back- and fore-sights are being taken, to minimise the slight error arising from "curvature" and "refraction."

As an example of levelling by this instrument we may take the line of section running across the area surveyed (Part I.), commencing at a milestone in the S.E. corner (fig. 8). On this the "broad-arrow" has been cut and it is shewn thereby to be an Ordnance Bench-mark, the height of which, above the sea, is ascertained to be 365 feet. We may take the distances, where our line crosses roads, brooks, and so on, from the map, reserving the example of measuring by chain for the theodolite illustration. But these points are too far apart and at too great a difference of level for the instrument to be placed once only between each two, we must therefore take intermediate observations.

> *Note.*—In running a set of levels by this instrument and scaling the distances of definite points from the map (the intervening surface line being sketched in by eye and hand), it is immaterial whether the intermediate levels be taken along the line or by a more convenient route, so that each of these points be made a station for an observation.

The Bench-mark, that is, the milestone of which the reduced level is known, must be the starting-point, and having drawn on the map our proposed line therefrom and passing by the church, we proceed in the following manner. The instrument is set up on the road a few chains from the B. M., and the plate-screws turned until the spirit-tube indicates that its position is in every direction horizontal. The assistant holds up the staff upon the milestone, so that its base coincides with the upper line of the "broad-arrow" and a reading is then taken therefrom. This must be entered in the level-book as a "back-sight" (10·90), and a second look taken through the telescope for the purpose of checking the accuracy of the first reading. The man then takes the staff on along the road, which runs about in the right direction, to a distance roughly equal to that of the instrument from the milestone. A reading is taken upon it (2·10), entered as a "fore-sight," checked by a second reading, and the level carried forward some chains beyond the staff when all the operations are repeated. The staff will then be turned round to face the instrument in its new position, but care must be taken that the back- and fore-sights are read off without other alteration in its position.

The levelling is thus carried on by the road, just off the real line, to the cross-ways, when it must be managed for the staff to be placed on the road where it is cut by the section line, this being one of the points to be scaled from the map. Then the line is followed, or nearly so, in the direction of the cottages by which it passes, down the escarpment (where shorter sights will be necessary owing to the rapid fall), by the well, across the brook, past the church, and ends by the stream on the W. side of the map.

The level-book will best explain the manner in which the details are observed and entered, as they come under notice or require specification.

From . . . Milestone, N. 35° W. passing by . . . Church.

Back-sight.	Inter-me-diate.	Fore-sight.	Rise.	Fall.	Reduced Level.	Dis-tance.	Remarks.
					365·00		B. M. Milestone.
10·90		2·10	8·80				
12·17		1·50	10·67				
13·00		·40	12·60				
12·08		1·00	11·08				
13·10		1·15	11·95				
			55·10		420·10		Boundary of Loam.
9·94		·74	9·20				
14·00		1·00	13·00				
12·50		·40	12·10				
11·60		·66	10·94				
9·90		1·10	8·80				
9·10		·73	8·37				
9·63		2·00	7·63				
			70·04		490·14		Road.
12·08		·40	11·68				
14·00		·08	13·92				
13·41		1·04	12·37				
12·90		3·11	9·79				
11·17		·78	10·39				
9·87		1·17	8·70				
13·93		·90	13·03				
			79·89		570·03		Top of Church Escarpment.
5·03		7·18		2·15			
3·70		8·10		4·40			
2·40		10·90		8·50			
1·09		12·87		11·78			
·18		13·86		13·68			
1·03		12·90		11·87			

Back-sight.	Inter-me-diate.	Fore-sight.	Rise.	Fall.	Reduced Level.	Dis-tance.	Remarks.
					570·03		Top of Ch. Escarp.
1·10		13·00		11·90			
·04		13·75		13·71			
·17		12·81		12·64			
1·00		13·80		12·80			
2·25		10·70		8·45			
				111·88	458·15		Top of Lower Escarpment.
3·70		8·05		4·35			
2·10		12·14		10·04			
1·73		12·80		10·07			
·03		13·91		13·88			
1·18		12·76		11·58			
·93		13·01		12·08			
10·08		3·71	6·37				
3·18		8·20		5·02			
1·11		11·71		10·60			
1·00		12·90		11·90			
2·11		13·11		11·00			
·19		13·21		13·02			
1·30		11·40		10·10			
2·00		12·10		10·10			
			6·37	133·74			
				6·37			
				127·37	330·78		Boundary of Chalk.
3·17		12·75		9·58			
1·14		13·80		12·66			
·19		13·10		12·91			
1·02		13·70		12·68			
2·00	10·40			8·40	274·55		Boundary of U. Green-sand.
		11·90		9·90			
5·80		4·20	1·60				
3·20		8·90		5·70			
1·00		12·81		11·81			
1·11		13·00		11·89			
·03		13·41		13·38			
1·08		13·85		12·77			
1·17		12·74		11·57			

Back-sight.	Inter-mediate.	Fore-sight.	Rise.	Fall.	Reduced Level.	Distance.	Remarks.
					330·78		Boundary of Chalk.
·19		13·40		13·21			
3·76	1·08		2·68		197·00		By Well (110 feet deep).
		12·84		9·08			
2·20		10·10		7·90			
3·00		12·84		9·84			
2·17		8·41		6·24			
2·40		13·19		10·79			
			1·60	182·11			
				1·60			
				180·51	150·27		Stream.

The levelling is carried on in the same manner over the chalk outlier, care being taken to obtain the heights at, or as nearly as possible upon, the geological boundaries.

It will be seen from the above example of a level-book that the heights of certain definite stations only are worked out—those of the others being unnecessary, and probably off the line. The method of procedure is, to add up the "rises" and "falls," to subtract the smaller sum from the larger—the remainder to be added to or deducted from the height of the last station where it was calculated, according to the predominance of "rise" or "fall," as the case may be. In making the additions, all "intermediate" sights are to be disregarded, the calculations at those places being enclosed between two lines to indicate that they are not to be included. The final result may be checked by adding together all the "back- and fore-sights," deducting the one amount from the other, and the result from, or adding it to, the last height obtained.

Plotting—from heights.—Before considering a different style of taking surface levels, it will be well to see how the results of the proceeding and similar observations are plotted; that is, reduced to the form of a representative drawing. The method in all of them is the same, a straight line is drawn on the long slip of paper usually employed, to represent the datum-level, whether it be the sea-level, 1000 feet below it, or any other that may be adopted. Along this line are set off by scale the distances of each station in succession—and at right angles to it lines in pencil are drawn through all these points. The reduced level of each station is then scaled off along its vertical line and another line is sketched in, running through all these reduced level points, and as nearly as may be conforming to the shape of the ground between. This last operation will be facilitated and greater approach to accuracy secured by sketch lines made in the field on the plain side of the level-book.

If the section is being made from ordnance bench-marks, the proceeding is exactly the same—if from contour maps, with this difference only, that every point where the line crosses a contour is considered a station, the distance scaled off and the height inserted accordingly.

By Theodolite.—The method of taking levels by the theodolite differs from that by the level, in the former having its visual line not in a horizontal plane, but inclined at various angles to the horizon according to the slope of the ground between the stations. The telescope, cross-wire, and spirit-level are the same, and the instrument may be used as a level if desired. But the telescope is swung to move vertically, and the angle at which its line of sight coincides with the object to which it is directed is indicated on the graduated arc attached to and which moves with the telescope—the amount of inclination being read off with the greatest accuracy by means of a vernier scale.

For levelling by theodolite it is necessary that the instrument be placed on the line of section (unless correct heights at definite points only are required), and that correct measurement be made of the distance between the instrument and the places at which observations are taken—for it is evident that an inclined plane gets to a greater or lesser height at every additional portion of distance.

The instrument is placed on the line by compass-bearing, not necessarily ascertained every time it is set up, for it will frequently happen that an object at considerable distance is seen to be in the correct line, and by chaining straight towards such object the desired end may be attained with much less trouble. When, to get the proper line of direction, a bearing has to be taken, the needle beneath the telescope is set free and the instrument revolved on its horizontal plates until the needle comes to rest at the proper angle—allowance of course being made for magnetic variation.* In this, and all other manipulations of the theodolite, the process is commenced by bringing it *nearly* into the required position and then fixing it by the "clamping screws," the operation being completed to the greatest nicety by means of finely-cut "tangent screws" provided for the purpose. The divisions of the arc, plates, and verniers

* *Ante*, p. 9.

are so minute that a pocket-lens must be used in reading off the indications.

The measurements are made along the surface, flat or inclined as the case may be, with a chain 22 yards (=$\frac{1}{80}$ of a mile) in length, divided into 100 links. The chain, made with strong wire, has a handle at each end and a brass or other mark every ten links to aid in counting the odd parts of each admeasurement. Ten iron arrows, with pieces of red cloth on each, are carried by the leading chain-man, who puts down one at the end of every chain measured—when the extent of ten chains is reached the arrows, picked up in passing by the chain-man at the rear-end, are restored to him, and a note is made of every such ten chains passed over.

We must secure the services of three men, or boys, two being required for chaining, and the third for assistance in the taking of our observations. The work can be done with two only, but with a third it is gotten over much more expeditiously—of the three men, he who is most to be relied on for care and accuracy, or is accustomed to the work, should be put in the rear of the chain.

As every spot where the instrument is placed will be constituted a "station," the height from the ground of the objects on which sights are taken should be about the same as that of itself, viz. 5 feet—the visual line will then be carried from end to end at a uniform distance of 5 feet from the surface. A light staff of that height, with a cross-piece at top painted white, is a good thing to be carried by the assistant and placed by him on each place in turn where the observations are taken—or without this staff the sight may be taken on the assistant himself, as on the top of his head or the line of his eyes.

But the fore- and back-sights at an object must always be taken on it when at the same level; if this be done it does not matter about its being a little too high or a little too low relatively to the surface. For instance, it may sometimes be convenient to place the man, with or without the staff, on the top of a bank or on a gate—this will cause a *local* error of a few feet, but if both fore- and back-sights be taken on it without alteration in its position a *constant* error is avoided, which would otherwise be carried on to the end of the section.

If the line of section, across the map (figs. 5 and 8), were to be run by theodolite, the proceedings would be somewhat as given below. Assuming that the start be made from the milestone, which is also an ordnance B. M. 365 feet, the first thing to be done is to find the line (N. 35° W.) along which the section has to be run. The instrument is set up and manipulated by the plate-screws until the spirit-levels indicate that it is in a horizontal position, then turned round, with the needle free, until the latter comes to rest at 13° (35° W.—22° variation = 13°), the final adjustment having been made by the tangent screws. The telescope being unclamped is free to move vertically (only), and as it now points directly along the line of section, any objects in the centre of its field are also in the line and may be pointed out to the chain-man for his guidance. We may assume that a tree in this instance comes in, and beyond that the line passes just between two cottages seen at a long distance. After seeing that the leading man has his ten arrows, and that the chaining has been started in the direction of the tree, we place our assistant at the milestone with the staff on the B. M., and walk on to where a rise in the ground begins. In doing so we may observe whether the chain-man is directing his leader properly along the line—he should do this by looking along the chain and by a wave of the hand to either side, getting it ranged properly before the arrow is stuck in the ground. Having set up the instrument and booked the length, ten chains, in the level-book, we send on the chain-men to measure to the next fence. Adjustment for horizontality having been made, we direct the telescope back to the head of the staff on the B. M., clamp it, and by turning the tangent-screw get the cross-wire exactly to coincide therewith. We read off the result as a depression of 0° ·50′, and enter it in its proper column, making a little cross also in the column headed "Back-sight" to indicate that this is such, take another look through the telescope and at the reading to see that there is no mistake, and beckon the assistant to come on. He is sent on immediately to stand in the fence to which the chain-men have measured, in such a position that he can be seen both from the instrument and from the ground beyond. Another sight is now taken on the staff and entered, this time as a "fore-sight"—again checked by repetition, and we walk on to find that the measurement from the instrument to the fence was 4 chains 33 links. We go on again with the chain-men, set up the instrument, take a back-sight, and, in fact, repeat exactly the former operations. As stations for the instrument and for the staff, the spots on the line where changes occur in the shape of the ground should be selected, the smaller features being sketched in as we proceed—of this, the copy of the level-book given below will afford an illustration.

From......Milestone N. 35° W. passing by ...... Church.

Station No.	Forward.	Back.	Station No.	Elevation.	Depression.	Distance.	Remarks.
1						0·00	B. M. Milestone, 365′.
		x	2		·50	10·00	
3	x			1·5		4·33	
		x	4		6·20	6·33	Slight rise between. Boundary of Loam about midway.
5	x			8·0		6·20	Road.
		x	6		4·0	7·00	
7	x			4·0		6·50	
		x	8	1·30		3·00	Rise between.
9	x				16·30	4·33	
		x	10	·45		5·50	Hollow between.
11	x				5·	1·80	
		x	12	11·10		4·30	
13	x				5·30	4·00	
		x	14	9·0		3·50	Boundary of Chalk.
15	x				9·35	5·50	„ Green-sand.
		x	16	6·28		4·00	
17	x				7·30	4·40	Well, 110′ deep.
		x	18	7·30		6·30	Stream.
19	x			16·30		7·80	Boundary of Green-sand.
		x	20		17·10	3·80	Boundary of Chalk.
21	x			11·5		4·00	. . . By — Church.
		x	22	5·30		7·00	Boundary of Chalk.
23	x				5·55	4·50	
		x	24	20·30		1·30	(Rise between) Boundary of Green-sand.
25	x				8·10	8·00	
		x	26	5·5		7·70	Slight hollow between.
27	x				7·10	3·30	Stream.

It will sometimes occur that the face of a cliff or quarry, of a sharp or rugged slope, is such that it cannot possibly be measured with the chain. The height must then be ascertained by means of two (or more) observations with the theodolite; one at some distance from the base, and the other nearer thereto by a few chains—the length and the fall of the ground between the points must of course be accurately determined. One of the observations can be made from the last station, and the other in advance of it, the sights being taken on the staff or other object upon the summit. These with the length and fall between the points being plotted as a diagram, and with reference to a temporary datum line, will give at the intersection of the angles the height and position of the object relatively to such datum (see fig. 18).

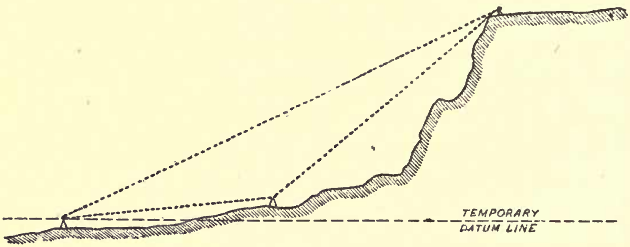


Fig. 13.

Various expedients may with advantage be occasionally adopted under exceptional circumstances, as for instance, in coming to a field of standing corn, which would be injured by the chain-men measuring through it, or a tract of marsh land flooded so as to be impassable. In the former case the exact level of an accessible object on or near the line may be transferred across the field, by clamping the instrument at zero, and noting where the cross-wire cuts some object on the other side; the distance must be judged, or it may perhaps be scaled from the map. In the other supposed case, the staff or man should be placed at a station by the edge of the water on the near side of the marsh, and in a similar position when starting again from the other side; the space between the two points will of course be level and the distance must be obtained as before.

Sometimes also a great deal of useless labour may be saved by going somewhat off the line, as round a wood or a village, care being taken to note the horizontal angles at which the line is left and rejoined, also those and the distances between all the intermediate stations. These being afterwards laid down shew the line actually levelled, and the distance between the points of departure and return can be scaled off—the ascertained difference in height will require no alteration.

Plotting from Angles.—The method of plotting theodolite observations varies somewhat from that described, and must be performed with great care for the result to be satisfactory. A straight line is drawn on the long strip of paper to represent the "datum line," sea-level or otherwise, and another line vertical thereto, near the left-hand end of the paper, which should be also the most southernly end of the section. On the vertical line, which corresponds to station 1, set off the height above datum of the B. M., in the case supposed, 365 feet. Then with a protractor of circular or semi-circular shape, and made in horn or other transparent material, lay down a line inclined to the datum line as many degrees and minutes as are recorded in the first observation. This being a "back-sight" and "depression" means of course "elevation" in a forward direction, the line must therefore rise from the bench-mark. The angle is best laid down, or at all events pricked off, by the datum line, from the point where crossed by the vertical line (on which point the centre of the protractor would be placed), and then transferred to its proper position as starting from the bench-mark. The measured distance is then scaled off along the inclined line, and another vertical line in pencil drawn through the measured point and through the datum line. This point is the second station, and a figure 2 is made below it for the convenience of future reference. Another line is now laid down in a similar manner for the "fore-sight;" this being an "elevation" forwards rises in the same direction as the one already plotted, is laid down, measured off, and numbered. The succeeding observation is a "back-sight" and "elevation," therefore "depression" forwards, and will be laid down with a different inclination from those previously drawn.

These lines of course do not accurately represent the curved parts of the surface, but give correct heights at the points selected for stations; the line, when inked in between, must sweep naturally through these points, and the sketch lines in the level-book supply the shape of the intervening ground. Wherever a station is on a road, or by a stream, a pit, and so on, the fact must be recorded on the section; and wherever the line crosses or passes by such points between the stations, note must be made of the intermediate measurement to them that their position may be correctly indicated. The section, fig. 19, has some working lines dotted at the left hand; these represent the stations, and in practice would be drawn in pencil, to be erased when the surface line with the roads, &c., had been drawn in Indian ink.

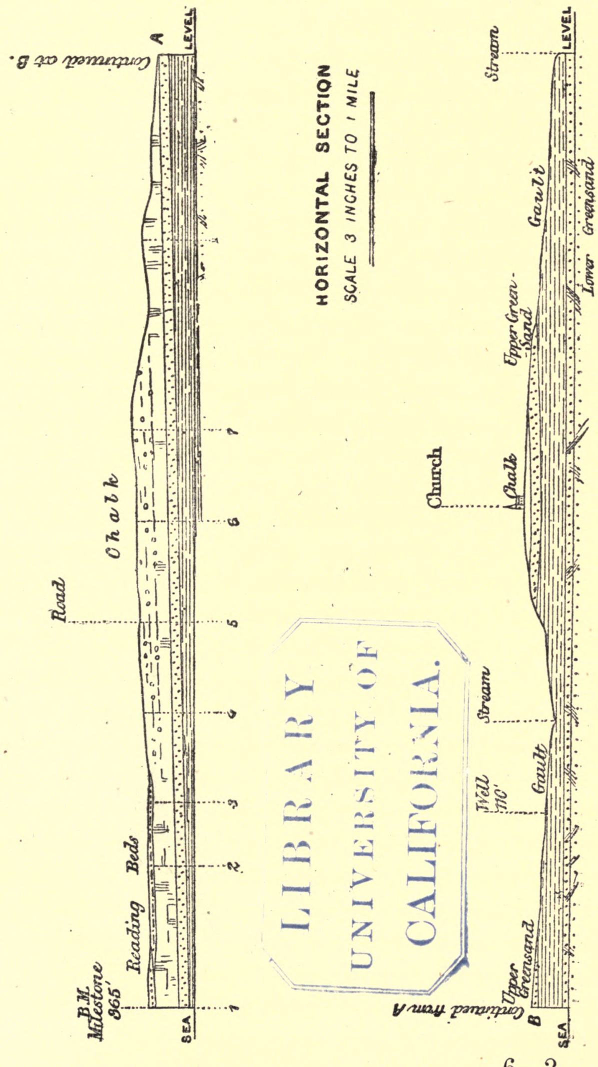

HORIZONTAL SECTION
SCALE 3 INCHES TO 1 MILE
Continued at B.
A
LEVEL
SEA
B.M. Milestone 865'
Reading Beds
Chalk
Road
1
2
3
4
5
6
7
Continued from A
B
Upper Greensand
Gault
Well 110'
Stream
Church
Chalk
Upper Green-Sand
Gault
Lower Greensand
Stream

Fig. 19.

Filling in Geology.—The geological details are filled in by aid of the boundary lines on the map, of the particulars observed in exposed sections and ascertained from wells or borings, and to a great extent by inference from such evidence. The lines of boundary and outcrop are scaled off from the map, or their position noted in the measurements along the line of section levelled, the beds drawn with the proper inclination, true or apparent dip as the case may be, and with all known faults, flexures, and contortions—dotted lines only being used where the details are uncertain. In this operation the table given at page 50 will be found of service, but care must be taken to allow for unevenness of the ground, by drawing a horizontal line to work from through the point at which the calculations are to be applied.

Apparent Dip.—Frequently the line of section will run not in the direction of the dip, in such cases the inclination of the beds must be shewn as it would appear in a section cut through them along that line. The difference can be found by calculation, but is more readily ascertained by diagram, or on reference to a table constructed by the late Mr. J. B. Jukes, and published by him in the Appendix to the "Geology of the South Staffordshire Coal-field."—*Mems. Geol. Survey.*—It is given also in an abridged form in his "Manual of Geology," with the addition of some valuable hints on the construction of geological sections.

In the article previously quoted (p. 49) Mr. Dalton gives a method of finding the apparent inclination in a direction oblique to that of the true dip.

"*Problem.*—To find the apparent angle in any required section, from the full dip and deviation of its direction from that of the section (fig. 20).

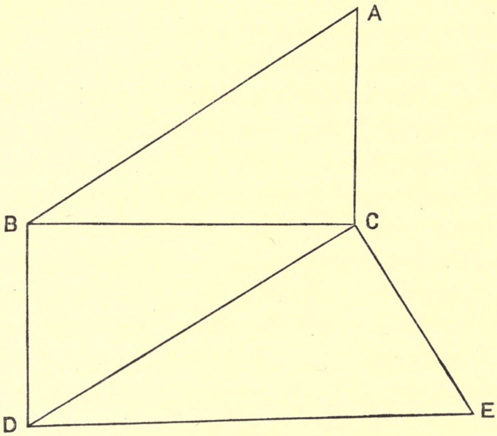


Fig. 20.

"Construct the right-angled triangle A B C, with A B C equal to the full dip; also the right-angled triangle B C D with B C D equal to the deviation; lastly the right-angled triangle C D E, in which C E is equal to A C.

"Then C D E is the required apparent angle.

"*Proof.*—If A B C be a vertical plane along the full dip, and C D E the vertical plane of section, B C D will be a horizontal plane, and A C, C E will coincide, so that B D, A E will be the plane of stratification, giving the apparent angle C D E along the section."

In the section, fig. 19, illustrating the geological structure of the area surveyed, the boundary lines of the chalk and upper green-sand would be scaled from the map, or their position ascertained while chaining as the heights were taken by aneroid, level, or theodolite. The N. and S. boundaries of each, so far as the outlier is concerned, would be united by straight lines, or the actual lines of division would perhaps be more accurately represented by being slightly depressed in the centre. Dotted lines across the valley between the outlier and the main mass, passing through the points of boundary, will give the inclination at which they commence to dip beneath the surface; farther S. the chalk is shewn dipping at an angle of 2° 30′; the true dip is 3° but the section line is oblique thereto, the deviation being 28°, and the apparent dip of 2° 30′ is found either by table or diagram. The thickness of the Gault at the well being known, 108 feet, the base of the deposit can be shewn there and prolonged by dotted lines, as provisional only until the section shall have been extended northwards to the boundary of the formation.

PART III.
LITHOLOGY.

CHAPTER I.

DETERMINATION OF ROCKS.

Texture—Structure—Fracture—Lustre—Hardness and Effervescence—Specific Gravity—Reactions in the Wet Way—Blowpipe.

General Remarks.—The kinds of rock of which the crust of the earth is composed are as various almost as the rocks themselves. Rocks coming under the same denomination, such as clay, sand, and so on, have been formed during all geological periods, but vary more or less in their minor characteristics. This is owing mainly, as regards sedimentary deposits, to differences in the kind of the rocks (and the relative quantities of each kind) from which they have been derived—that is, in any area, and at any time subject to denudation. The resulting deposits differ accordingly, perhaps not so much that it shall always be possible to examine a specimen and say at once, "This belongs to such and such a formation," but it can be done in very many instances; and when it cannot, Palæontology must furnish the additional evidence. The eruptive and intrusive rocks vary also according to their age, although not to so great an extent, and from causes that are not so well understood.

But in consequence of the changes which rocks have undergone subsequent to their formation, it is not at all times easy to decide off-hand even to what class a specimen belongs—it must then be subjected to certain tests for its determination. There are simple tests for application in the field to ascertain the class of rock that is under examination ; and more delicate tests, involving the use of apparatus at home, by which the field results may be checked and extended. In many cases the simple directions given below will not go far enough towards accurate solution, but it will then be found advisable to consult such works as are devoted to the subject, or to obtain the assistance of a professed mineralogist for the ultimate determination of a difficult specimen.

In the many valuable works on Petrology and Mineralogy that have been published, the usual plan adopted, and in such works the only one possible, has been to name a rock or a mineral, and then to describe the results obtained by subjecting it to certain processes. But to the geologist, who goes into the field and encounters an unknown rock, this method of its determination involves a vast amount of labour and perseverance. The object aimed at in the compilation of the following Tables is to save much of this labour by *reversing* the process, tabulating the results obtainable, and deriving therefrom the kind of the rock subjected to experiment. This must necessarily be done within confined limits ; but a fair approximation to the desired result may be thereby obtained, with indications for more detailed operation. It should be unnecessary to insist upon what all text-books recommend, that an acquaintance with the appearance and characteristics of all ordinary rocks and minerals should be formed by careful study of cabinet specimens.

All the stratified rocks, except those organically and chemically formed, were deposited as clay, pure or impure—as sand or gravel, which differ from each other only in the size of their particles—or as an admixture of the two, sometimes with the addition of lime or other secondary ingredient.

Clay is simply mud derived from the waste of preexisting rocks. Generally, it consists of finely-comminuted silica, with about one-fourth of alumina, and as a rule may be considered a deep-sea deposit.

When indurated by pressure more or less vertical to the lines of bedding, it becomes divisible into laminæ, and is termed *Shale.*

When indurated by pressure in any other direction, it is *cleaved,* or becomes divisible into laminæ at right angles to the pressure, and is termed *Slate.* (See note below.)

In whatever form clay occurs, whether unaltered, as shale, or as clay-slate, it gives off when breathed on an earthy or slaty odour which is unmistakable.

Sand, also derived from the waste of existing rocks, consists mainly of silica, with a slight admixture of other minerals. When finely-bedded, it has been deposited in tranquil water;* when the lines of stratification intersect each other at various angles, it is *false-bedded,* and has been formed in a current,

* Except in the case of "blown sand"—see Jukes' "Manual," p. 378.

fluviatile or marine. When exhibiting "ripple-marks,"* it indicates a shore-line; when bound together by a cementing material, it becomes *Sandstone,* or, if coarse-grained, *Grit.*

Gravel consists of pebbles derived from neighbouring rocks, angular or rounded according to the degree of trituration to which they have been subjected. It is formed by rivers, or by marine currents at no great distance from the shore.

When bound together by a cementing material, it becomes, if the pebbles be more or less rounded, a *Conglomerate, or Pudding-stone;* if the fragments be perfectly angular, a *Breccia*—in either case representing a shore-line.

Clay and sand mixed, in varying proportions, form *Loam, or Brick-earth.*

Clay, with the addition of Lime, one-tenth or more of its substance, becomes *Marl,* and in a dry state breaks up into cubical fragments.

Marl, when indurated, becomes divisible into laminæ, and is termed *Marl-slate.*

Note.—"Bands of colour may sometimes be observed on the sides of Slates, often coinciding with slight changes of grain or texture; these mark its original stratification. But care must be taken in field observations not to rely too implicitly on mere bands of colour in slate rocks, unless they coincide with bands of various texture, which may always be trusted to show the original layers of deposition."†

To ascertain the kind of any rock exposed in a quarry

* Lyell's "Students' Elements," p. 21.

† Jukes' "Manual of Geology," p. 220. See also an excellent cut

or elsewhere, a fragment should be detached from a part that has been least subjected to the action of the weather; for the composition of a "weathered" surface may have been very materially modified. Some rocks will be thus changed into a substance totally different from their original state, and all are in colour and hardness more or less thereby affected.

Having selected a suitable portion of the rock, let a good-sized piece be broken off by chisel or hammer; this can afterwards be reduced—its most characteristic-looking part being chosen—into a fair hand specimen. In using the hammer for "stone-breaking," it should be borne in mind that the fracture will follow, as nearly as is possible, the line of the blow, the force of the descending implement (itself stopped by contact) passing on in the same direction, unless turned aside by the mass being too rigid to be broken through. A fissile rock may thus be split up into slabs by blows on the edge; a piece broken off at right angles to the bedding by a direct blow on the surface; and a projecting corner may be chipped off a very hard and solid rock by well-directed blows, when otherwise fragments are unobtainable. It is also worthy of remembrance that one good swinging blow is worth a dozen minor taps, and the risk is no greater of a resulting fracture to the hammer-handle.

The rock to be determined should be broken, with as little chipping as may be, into a square fragment, not a rounded lump, the larger surfaces representing the lines of bedding, with the others at right angles or there-

at p. 221, representing the planes of cleavage and original stratification.

abouts. The best observable edge is thus obtained; and if the specimen is to be preserved, it may with advantage shew one weathered side, and should not be too large for portability.

Texture.—The rock or mineral is first examined for "texture;" this may be very apparent, but if not readily decided, it must be observed with a pocket lens of one, two, or three powers as may be found requisite. This point should if possible be settled; but when doubtful under the lens, look for lines of varying colour as signs of stratification. The texture may be either—

CRYSTALLINE—in which the crystals are uniform and apparent, as in Quartz
Confusedly-crystalline—as in Granite
Sub-crystalline—as in some Limestones
GLASSY—resembling Glass—as in Obsidian.
COMPACT—or homogeneous—as in Flint
GRANULAR—made up of distinct and somewhat rounded grains—as in Sandstone
LAMELLAR, LAMINATED, FOLIATED—consisting of thin plates or layers, the laminæ being in the lines of bedding—as in Mica, Schist, &c.
CLEAVED—consisting of thin plates or layers, the laminæ being transverse to the lines of bedding—as in Clay-slate
FIBROUS—resembling fibres—as in Fibrous Gypsum
EARTHY—soft and friable—as in Shale
PORPHYRITIC—enclosing larger embedded crystals—as in some of the Cornish Granites.
VESICULAR—full of little cells or versicles—as in Pumice.

Structure.—The "structure" also of rocks must be noticed, some being distinctly *Bedded,* others *Massive* or in large masses broken in varying directions. Some are *Jointed,* divided by joints into blocks, or *Columnar,* when the blocks resemble columns; others are *Amorphous,* where no bedding or other structure is presented. Some rocks are termed *Slaggy,* these are like furnace-slag, others *Scoriaceous,* which are cinder-like in appearance.

Fracture.—The character of the broken surface or "fracture" affords useful indication of the kind of the rock or mineral under examination, when taken in connection with other peculiarities. The usual forms of fracture are:—

Conchoidal	=	Shell-like, as that of Flint		
Even	=	Flat	„	Felstone
Uneven	=	Rough	„	Serpentine
Splintery	=	Jagged	„	Graphite
Earthy	=	Irregular	„	Chalk

Lustre.—After the texture of a specimen has been determined, and its fracture noted, the "lustre" of its freshly-broken surface requires observation. This character distinguishes a rock, whether it possess a crystalline or any other texture; for instance, it does not at all follow that because a rock is crystalline, its lustre must be vitreous, or that it should not be such when the texture is compact or granular. There are many kinds and degrees of each kind of lustre, the most usual being:—

Vitreous, like glass
Sub-vitreous
Resinous, like resin
Pearly, like that of a pearl
Silky, like silk

Metallic, like the ordinary lustre of metals
Sub-metallic
Adamantine, like that of a diamond.

Hardness and Effervescence.—The tests by which, in the field, the nearest approach can be made to the desired result are its "hardness" and "effervescence." The former is roughly determined by means of the steel blade of a pocket-knife, the latter by application of dilute nitric, sulphuric, or hydro-chloric acid (usually about one part acid to five water). A rock or mineral soft as Talc or Rock-salt may be scratched by the finger-nail; between those and Apatite, by the knife with ease; beyond that, and including Orthoclase Felspar, with some degree of force; while those of greater hardness are not marked at all by the steel. A drop of dilute acid applied to the fresh fracture will cause effervescence—rapid, if the specimen consist of pure carbonate (of lime or otherwise); slow, if only partly composed of carbonate; and none whatever if it be a sulphate or a silicate. The following table is easily remembered, and applies in nearly all ordinary cases. The exceptions are not numerous, and they present well-marked characteristics of their own; in such cases further tests if necessary must be applied at home. In practice, so many slight variations are found, that they are incapable of simple classification; but then judgment must guide the observer, and an acquaintance with cabinet specimens will be found of great service, surpassed only by actual field experience.

If a rock or mineral:—

Scratch *with ease* and effervesce *freely*, it consists of Calcite or Limestone.

Scratch *with ease* and effervesce *slowly,* it consists of Magnesite or Dolomite.

Scratch *with ease* and effervesce *not at all,* it consists of Sulphates or Silicates.

Scratch *with difficulty* and effervesce *not at all,* it consists of Silicates.

Scratch *not at all* and effervesce *not at all,* it is a pure Silicate when crystalline, and Siliceous when compact.

Scratch *not at all* and effervesce *slowly,* it is calcareous Sandstone when granular.

Actual determination at home of the hardness of a mineral is made by comparison of the specimen with others of which it is known, the scale arranged by Mohs being the one generally adopted.

HARDNESS.

Scratched by the nail.	1. Talc. 2. Rock-Salt.
Scratched by the knife with ease.	3. Calc-Spar. 4. Fluor-Spar. 5. Apatite.
Scratched by the knife with difficulty.	6. Felspar (orthoclase).
Cannot be scratched by knife or file.	7. Quartz. 8. Topaz. 9. Sapphire. 10. Diamond.

The test is made by "rubbing the specimen over a tolerably fine-cut file, and noting the amount of powder, and the degree of noise produced by so doing. The less the powder and the greater the noise the harder will be the mineral. On the other hand, a soft mineral will yield much powder, and but little noise. The noise and amount of powder should be compared with that produced by minerals which are used as standard examples. The trial may also be made by endeavouring to scratch the specimens enumerated in the list with the mineral under examination. If, for example, the mineral will scratch Felspar and will not scratch Quartz, it will have a hardness *between* 6 and 7.

"During these trials the 'colour' and 'lustre' of the streak should also be noticed."* "When a mineral is scratched, the colour of the scratched surface frequently differs from that of the original surface, and if the abraded powder be rubbed on paper, it leaves a mark of a peculiar colour. This is called the streak, and in some of the metallic minerals it is very characteristic."†

> *Note.*—In all the Tables here given only an approximation is intended, the *averages* of hardness and specific gravity inserted and the more simple of the tests for solubility and blow-pipe analysis. For more accurate and for *ultimate* determination of any particular specimen recourse should be had to some of the works specially devoted to the subject or to the professed mineralogist. A list is given at page 117 of some of the works which may with advantage be consulted.

Specific Gravity.—The "specific gravity" of a body being the proportion that its weight bears to that of an equal bulk of distilled water (the latter being taken as unity), it is evident that if such body be weighed, first in air, then in distilled water, the resulting loss

* "Mineralogy." Rutley. Murby's Series, 1874, p. 39.

† "Mineralogical Tables." Jewesbury. Murby's Series, 1873, p. 9.

of weight represents that of an equal volume of the water, displaced by immersion. Therefore the weight of the substance in air is to the loss of weight (*i.e.* the weight of the water) as the specific gravity is to unity—consequently the weight in air, divided by the loss, will give the required specific gravity.

A delicate balance on a stand with minute weights is required for the operation, one pan having a small hook beneath from which the specimen to be tested is suspended by a fine platinum wire—a few grains of sand, added after the thread is attached, will bring the scales into equilibrium. The actual weight of the suspended object is first to be ascertained, then there is placed beneath it a small vessel containing the water in such position that it shall be completely immersed during the second weighing operation.

Reactions in the Wet Way.—As a very useful addition to the particulars given under the head of "solubility" in the table of tests, the following list of "Reactions in the wet way" has been copied from Rutley's "Mineralogy," p. 22.

Substances.	*Reaction.*
Carbonates.	Effervesce when treated with dilute acids (either hydrochloric, nitric, or sulphuric), owing to disengagement of carbonic acid gas.
Sulphates.	Do not effervesce on the application of acids, but when in solution, a drop of chloride of barium will produce a dense white precipitate of sulphate of baryta.

Substances.	*Reaction.*
Nitrates.	Give off fumes of nitric acid when concentrated sulphuric acid is added.
Phosphates.	In solution give yellow precipitates on the addition of nitrate of silver or molybdate of ammonium. These reactions usually take some time.
Chlorides.	Give a white curdy precipitate when nitrate of silver is added to their solutions.
Fluorides.	When treated with strong sulphuric acid, give off fumes of hydro-fluoric acid, which roughen or etch glass.
Silicates.	Many silicates gelatinise when heated in concentrated acids. The silicate should be finely pulverised.

Blow-pipe.—"The student ought to accustom himself to the use of the blow-pipe, as an instrument to aid him in the determination of rocks—much assistance may be obtained in this way. No field geologist should consider his outfit complete if it does not include a blow-pipe, with the requisite reagents."* For the simple experiments, the results of which are given in the last column of the table, much apparatus is not required. "A blow-pipe of brass or German silver with platinum point, an oil-lamp with a broad rectangular wick, a piece of platinum wire, and a flat lump of wood-charcoal about six inches long for a support.

"The blow-pipe flame is produced by forcing a small continuous stream of air through the flame of the lamp

* "Student's Manual of Geology." Jukes and Geikie. 1872.

in a more or less inclined direction. The stream of air must be constant and regular, also properly directed and applied. It is in the power of the operator to direct either an *oxydising* or a *reducing* flame upon the body he subjects to its action.

"In order to obtain a reducing flame (for depriving a substance of its oxygen) the nozzle of the blow-pipe is held in an inclined direction parallel to the surface of the wick and just touching the exterior surface of the flame, a bright yellow flame will be thus produced. An oxydising flame (for bringing about the oxydation of a substance) is obtained by keeping the nozzle at the same inclination, introducing it into the flame to about one-third the breadth of the wick, and blowing a somewhat stronger blast—the flame so produced is of a pale blue colour and almost invisible by daylight.

"If a small fragment of an oxydisable substance be held just beyond the point of the oxydising flame it becomes intensely heated, and, being exposed freely to the action of the surrounding atmosphere, it is rapidly oxydised. This flame, on account of its great heating power, is also employed in order to ascertain the fusibility of various substances, and for effecting fusions in all cases in which a reducing action is not essential.

"When any substance is submitted to the action of the reducing flame it should be so held as to be entirely surrounded by the yellow flame, and protected from the oxydising action of the air; but this condition being fulfilled, it should be held as near as possible to the point of the flame in order to gain the greatest amount of heat."*

* "Scheerer and Blandford on the Blow-pipe." 1864.

CHAPTER II.

DETERMINATION OF ROCKS AND MINERALS—*continued.*

Table of Tests, *in the Field—at Home*—Metals—Tests—Microscope—Chemical Analysis—List of Books of Reference—Peculiarities of Structure, *Concretions, Slickensides*—Note on Metamorphic Rocks—Cabinet Specimens.

TABLE OF TESTS, for application in the field.

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence.	Colour.	Streak.
Crystalline	Conchoidal	Vitreous	With ease	Rapid	White or tinted	White or greyish
occurs also						
Compact	,,	,,	,,	,,	,,	,,
Earthy		Earthy	,,	,,	,,	,,
Granular	Flat	Dull	,,	,,	,,	,,
Fibrous	Splintery	Silky	,,	,,	,,	,,
Vesicular			,,	,,	,,	,,
Crystalline	Flat conchoidal	Vitreous	,,	Slow	White or greyish	White
occurs also						
Comp. and Gran.		Dull				
Crystalline	Conchoidal or uneven	Vit. inclining to Pearly	,,	,,	White or tinted	White or grey
occurs also						
Comp. and Gran.		Dull	,,	,,	,,	,,
Compact		Glistening	,,	None	White or slightly tinted	White
occurs also						
Granular		Dull	,,	,,	,,	,,
Crystalline		Sub-vitreous	,,	,,	,,	,,
,,		Silky	,,	,,	,,	,,

TESTS, for further determination at home.

The Substance probably is	Hard-ness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe.
CALCITE (Carbonate of Lime) *Varieties:* Limestone (Marble) Chalk Oolitic Limestone Satin Spar	3	2·6	Soluble in acid	Infusible, becomes luminous, and is reduced to quicklime
Calc-Tuff		(light)		
MAGNESITE (Carbonate of Magnesia)	4	3·	Soluble slowly in cold, rapidly in warm acid	Infusible, crackles and hardens
DOLOMITE (Carbonate of Lime and Magnesia) *Variety:* Magnesian Limestone	4	2·8	Soluble in warm acid	Infusible
GYPSUM (Sulphate of Lime) *Varieties:* Gypsum Selenite Satin Spar	2	2·3	Insoluble	Exfoliates and crumbles, becoming white and opaque

TABLE OF TESTS, for application in the field—*continued.*

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence.	Colour.	Streak.
Compact	Flat conchoidal	Resinous	With ease		White and amber	
Earthy			,,		Greenish brown	Shining
Crystalline	Conchoidal or uneven	Vitreous or sub-resinous	With difficulty	None	Various.	White
occurs also Comp.			,,	,,	(Brown)	
Concretionary			,,	,,	(,,)	
Crystalline Comp. or Gran.	,,	Vitreous	With ease	None	White, sometimes tinted purple, &c.	White
Crystalline	Conchoidal	,,	,,	None	White, tinted	White
,,		Vitreous, inclining to resinous	,,	,,	White or tinted	
Crystalline Comp. or Foliated	Splintery	Metallic	,,	,,	Black	Black and shining (*characteristic*)
Crystalline Compact			Not at all or with difficulty	,,		

Tests, for further determination at home—*continued.*

The Substance probably is	Hard-ness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe.
Allophane } Silicates of Alumina	3	1·8	Gelatinizes in hydrochloric acid	Loses colour and becomes pulverulent
Fuller's Earth } Silicates of Alumina	2			Fuses to porous slag
Apatite (Phosphate of Lime) *Varieties:* Phosphorite Coprolite	5	3·	Soluble in nitric acid	Infusible
Fluor Spar (Fluoride of Calcium	4	3·		Decrepitates and fuses to a clear bead, which becomes opaque
Rock Salt (Chloride of Sodium)	2	2·2	Soluble in water	Decrepitates, and tinges the flame yellow
Barytes (Sulphate of Baryta)	3	4·5	Insoluble	Decrepitates and fuses with difficulty; colours the flame yellowish-green
Graphite (Carbon)	2	2	Insoluble	Infusible alone
Silicates Impure do. { *Of some kind to be afterwards determined*			Insoluble	

TABLE OF TESTS, for application in the field—*continued.*

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence	Colour.	Streak.
Crystalline (sometimes Compact)	Conch. to uneven and splintery	Vitreous, to Pearly	With difficulty	None	White, pink	Greyish-white
”		Dull				
”					Colourless	
		Vitreous				
		”				
Compact	Even	”				
Compact (sometimes Crystalline)	Conchoidal, uneven	Resinous	”	”	White, tinted	Colourless
Crystalline	Imperfectly conchoidal	Vit. or sub-resinous	”		Greenish, brown, &c.	
Crystalline		Vit. inclining to resinous	”		Greenish-black	White or greyish
” (foliated)		Pearly-metallic	”		Green	Greenish
”	Uneven	Pseudo-metallic	”		Brownish green	
”		Pearly-metallic	”		Bronze	
Crystalline		Vit., horn-like	”		Green, brown, or black	Colourless
Compact		”	”		”	”
Crystalline *occurs also*	Conchoidal	Vitreous	Not at all	None	White or tinted	
Compact			”	”	Black or grey	
”	Flat		”	” (or very slight)		

TESTS, for further determination at home—*continued.*

The Substance probably is	Hardness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe.
FELSPAR. Orthoclase (Silicate of Alumina and Potash) *Varieties:* Common Felspar, Adularia ,, Glassy ,, (Sanidine) Felstone	6	2·5 to 2·6	Insoluble	Fuses on edge only into a white enamel; with borax forms a transparent glass
FELSPAR. Oligoclase (Silicate of Alumina, Soda, and Lime)	6	2·6 to 2·7	Insoluble	Fuses with difficulty to a clear glass
FELSPAR, Labradorite (Silicate of Alumina, Lime, and Soda)	6	2·7	Soluble in hydrochloric acid	Fuses easily to a clear glass
AUGITE (Silicate of Lime, Magnesia, &c.) *Varieties:* Diallage	5—6	3·2 to 3·5		Some varieties fuse easily into grey glass, others almost infusible
Hypersthene				Fuses easily to a grey or black enamel
Bronzite				Slightly fusible on thin edges
HORNBLENDE (Silicate of Lime, Magnesia, &c.) Hornblende Rock	5—6	2·9 to 3·4		Some varieties fuse easily into grey glass, others almost infusible
QUARTZ. Rock Crystal (Silica) *Varieties:* Flint	7	2·6	Soluble in hydrofluoric acid	Unaltered
Hornstone, Chert.				

TABLE OF TESTS, for application in the field—*continued.*

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence.	Colour.	Streak.
Granular				None (or very slight)		
Crystalline	Uneven	Vitreous	Not at all	None	Black	Colourless
Crystalline (foliated)	"	Pearly	With ease		Various	"
Compact (foliated)	"	"	"		White, or green	
		Resinous	"		Grey	
Crystalline (foliated)	"	Rather pearly	"		Dark olive-green	
Compact	"	Resinous	"		"	
Crystalline Comp. or Gran.			Not at all	None	White	
"			"	Slow	Various	
Laminated	Laminæ soft and earthy-looking	Glistening	With ease		"	
"	Do. hard and earthy-looking	Earthy	"		Dark grey	
"	Do. hard and glistening		"		"	
"	"		"		Black	
"	"		"		Green	

TESTS, for further determination at home—*continued.*

The Substance probably is	Hard-ness.	Specific Gravity.	Solubility.	Behaviour before the Blow-pipe.
Quartzite (altered Quartz Sandstone)				
TOURMALINE	7	3·		Fuses with difficulty
MICA (Silicate of Alumina)	2·5	2·9	Insoluble	Whitens, and fuses only on thin edges
TALC (Bisilicate of Magnesia) *Variety:* Steatite	1·5	2·65	„	Whitens and exfoliates, fusing with difficulty on thin edges to a white enamel
CHLORITE (Silicate of Magnesia, Alumina, and Iron)	1·5	2·7		Fuses with difficulty on thin edges
SERPENTINE ROCK (Silicate of Magnesia)	3·5	2·55		„ „ „ into enamel
			Consisting of	
SANDSTONE, pure			Quartz grains	
„ calcareous			„ „ in calcs. matrix	
„ micaceous			„ „ with scales of Mica	
SLATE, cleaved			Clay, metamorphosed	
MICA SCHIST			Quartz and Mica (varies)	
HORNBLENDE do.			Hornblende chiefly	
CHLORITE do.			Chlorite, with a little Quartz, Mica, &c.	

Table of Tests, for application in the field—*continued.*

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence.	Colour.	Streak.
Crystalline	Laminæ more or less apparent			Not at all	None	
Comp. to Crystalline				Along the inner border of weathered portion	Green, weathers brown	
Crystalline				”	Greenish	
”				”	Greenish-black	
Crystalline Granular					Dark grey	
Compact					”	
”	Conchoidal				Black	
”	Even	Vitreous			Grey, weathers white	
”	Sub-conchoidal	”			Black, varies	
”					Pink, brown	
”	Even				Grey	
” (or schistose)	Splintery				Grey, weathers white	
Glassy	Conchoidal	”			Brown or grey	
Vesicular						

TESTS, for further determination at home—*continued.*

The Substance probably is	Hard-ness.	Specific Gravity.	Consisting of
GNEISS			Quartz, Felspar, and Mica, in layers more or less apparent
DIORITE (Greenstone)		2·6 to 2·9.	Felspar (not orthoclase), and Hornblende
GABBRO (Greenstone)		2·8 to 3·	Labradorite and Diallage
HYPERSTHENE ROCK (Greenstone)		2·95	„ and Hypersthene
DOLERITE		3·	„ and Augite (with some titaniferous Iron)
Varieties:			
Anamesite		2·80	„ „ „
Basalt		2·95	„ „ „
FELSTONE		2·6	Felspar and Quartz (orthoclase)
Variety:			
Pitchstone		2·35	„ „ „
PORPHYRITE		2·65	Felspar (oligoclase or orthoclase), with Hornblende, Mica, &c. (rarely Quartz)
TRACHYTE		2·65	Felspar (orthoclase), sometimes with Sanidine (no Quartz)
Varieties:			
Clinkstone (Phonolite) (partly sol. in Hydro Chl. Acid)		2·6	Felspar (orthoclase), with Nepheline and sometimes with Hornblende, &c.
Obsidian		2·4	Felspar (orthoclase), in a completely vitreous condition
Pumice (Lava froth)		2·3	Felspar (orthoclase), in a cellular form

Table of Tests, for application in the field—*continued.*

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence.	Colour.	Streak.
Crystalline					Various	
Compact, &c.	Fibrous	Metallic, dull	With ease	None	Black, grey	Black
,,	Uneven	Vit., inclining to Pearly	With difficulty	Rapid	Greyish	White
Crystalline &c.	Conchoidal	Resinous	With ease	None	Black or brown	,, to reddish brown
,,	Uneven	Vitreous	With difficulty	,,	White, tinted	White
,,	Flat, even	Metallic	With ease	Rapid	Lead-grey	Lead-grey
Compact		Dull or glistening	,,		Olive-green	
Radiating, &c.		Pearly to Vitreous	,,		Blue	Blueish white
Compact, &c.	Conchoidal	Vitreous	,,	None	Green	Colourless
Crystalline &c.	Uneven	,, Pearly	,,	Rapid	Brownish	White
Concretionary						

TESTS, for further determination at home—*continued.*

The Substance probably is	Hardness.	Specific Gravity.	Consisting of	
GRANITE		2·6	Quartz, Felspar, and Mica	
Syenite			Quartz, Felspar, and Hornblende	
			Solubility.	Blow-pipe.
PYROLUSITE (Binoxide of Manganese)	2	4·9	Soluble in hydrochloric acid	Infusible alone. With borax, in outer flame gives an amethyst-coloured bead
CALAMINE (Carb. of Zinc)	5	4·25	Soluble in hydrochloric acid	Infusible alone
BLENDE (Sulphide of Zinc)	4	4·	"	" " (Evolves sulphurous acid)
SMITHSONITE (Silicate of Zinc)	5	3·35	Soluble in strong solution of caustic potash	Almost infusible alone
GALENA. Lead ore (Sulphide of Lead)	2·5	7·6	Soluble in nitric acid	Evolves sulph. acid, and yields on charcoal a metallic globule
GLAUCONITE (Silicate of Iron and Potash)	2	2·3		Fuses easily to a dark magnetic glass
VIVIANITE (Phosphate of Iron)	2	2·66	Soluble in hydrochloric acid	Fuses, loses colour, and forms magnetic globule
COPPERAS (Sulphate of Iron)	2	1·83	Soluble in water	Becomes magnetic: gives green glass with borax
CHALYBITE (Carb. of Iron)	4	3·8	Soluble in hot hydrochloric acid	Blackens, and becomes magnetic
Clay Ironstone				

TABLE OF TESTS, for application at home—*continued.*

Texture.	Fracture.	Lustre.	Scratched by knife.	Effervescence.	Colour.	Streak.
Reniform &c.	Fibrous	Sub-metallic	With difficulty		Red	Red
Crystalline &c.	Sub-conchoidal	Metallic	"		Steel-grey	"
Compact	Fibrous	Sub-metallic	"		Brown	Yellowish brown
Crystalline	Conchoidal, uneven	"	Not at all	None	Bronze-yellow	Greenish
"	Sub-conchoidal	"	"		Iron-black	Black
"	" or uneven	Adamantine or resinous	"		Black or brown	White
"		Vit., metallic	With ease	"	Sky-blue	Dark grey
"	Conchoidal, uneven	Metallic, dull	"	"	Lead-grey	Lead-grey
Compact (or fibrous)		Silky, dull	"	Rapid	Bright-green	Pale green
"		Metallic	"	None	Brass-yellow	Greenish black

TESTS, for further determination at home—*continued.*

The Substance probably is	Hardness.	Specific Gravity.	Solubility.	Blow-pipe.
HÆMATITE (Peroxide of Iron)	5·5 to 6·5	4·5 to 5·	Soluble in acid	
Impure varieties:				
SPECULAR IRON (peroxide of Iron)		5·		Infusible alone.
LIMONITE variety, Bog Iron-ore	5· to 5·5	3·6 to 4·		
PYRITES (Bisulphide of Iron)	6	5·		Fuses to metallic globule
MAGNETITE. Magnetic Iron ore. (Proto-peroxide of iron)	6	5·	Soluble in hydrochloric acid	Infusible alone
CASSITERITE. Tin ore (Binoxide of Tin)	6·5	6·7	Almost insoluble	" "
BLUE VITRIOL (Sulphate of Copper)	2·5	2·2	Soluble in water	With soda on charcoal yields a bead of copper.
COPPER GLANCE (Sulphide of Copper)	3·	5·6	Soluble in hot nitric acid	Fuses to globule of copper
MALACHITE (Carb. of Copper)	4	3·7 to 4·	Soluble in acids	Decrepitates, fuses, and colours flame green
COPPER PYRITES (Sulphide of Copper and Iron)	3·5	4·2		Fuses to a magnetic globule

The more common Metals,

their usual modes of occurrence, and tests* for approximate determination.

Metals are characterised by their peculiar (metallic) lustre and great specific gravity. Some are found "native," but they usually occur in the state of ores, that is, in chemical combination with other substances, generally in veins in the older rocks, or as concretions in interstratified beds.

The following Metals occur in a Native State :—

Gold, Silver, } In plates, nuggets, grains, and threads among the older rocks, or alluvial deposits derived therefrom.

Platinum, in grains.

Copper, in plates and threads.

The following Metals occur as Ores, in Veins :—

Silver.

Copper, as Blue Vitriol, Glance, &c.

Lead, as Galena.

Iron, as Vivianite, Copperas, &c.

Tin, as Cassiterite.

Zinc, as Calamine, Blende.

The following Metals occur as Ores, in Beds :—

Copper, as Malachite, Pyrites, &c.

Lead, as Galena.

Iron, as Clay-iron ore, Pyrites, Glauconite (disseminated grains), Chalybite, Hæmatite, Magnetite, &c.

Manganese, as Pyrolusite, Wad.

Zinc, as Calamine, Blende.

* *See* Preceding Tables.

Microscope.—"It often happens that neither the naked eye nor a good lens will help us to get at the composition and textural arrangement of fine-grained rocks, while the rough forms of analysis mentioned in the foregoing paragraphs are equally unavailing. In such cases much may be learnt by examining the rocks under a microscope. For this purpose a thin slice of any rock which it is proposed to examine is taken, ground smooth, and polished on one side.* The polished surface is then securely fastened with Canada balsam to a piece of plate-glass, and the other side is ground down until the section is of the required thinness and transparency. The preparation may be covered with a plate of very thin glass mounted with balsam on the slide, care being taken to exclude all air-bells, and to remove all traces of the emery powder and other substances used in the grinding and polishing process.

"A rock-section prepared in this way enables us to ascertain with precision the manner in which the different minerals are built into each other, and often throws a flood of light on the origin of a rock, and on the subsequent changes which it has undergone. It furnishes an opportunity of applying the delicate analysis of polarised light, and thus reveals points of structure in the composition of a rock which could not be ascertained in any other way."†

"When prepared slices are examined under the microscope, it is often surprising to see how minerals which

* Mr. Jordan (of the Mining Record Office) has invented an ingenious rock-slicing machine, which may be obtained from Messrs. Cotton and Co., Grafton Street, Soho, London.

† "Students' Manual of Geology." Jukes and Geikie. 1872.

have previously been regarded, and even analysed, as perfectly homogeneous substances, envelop vast quantities of minute crystals of other minerals."* Here comes in the use of the microscope; by its means we also "learn whether a rock, whose structure is too minute to be understood without it, is to be classed amongst the aqueous or the igneous series," and we discover "minute organisms, such as foramenifera, diatomaceæ, or faint vegetable traces in rocks, in which, without its help, nothing can be detected. The broken and often water-worn fragments of the aqueous rock, derived it may be in the first instance from the breaking up of igneous rocks, will at once reveal its origin.

"Igneous rocks are for the most part crystalline in their structure, although we must at the same time remember that many crystalline rocks have been formed directly from watery solution. Gypsum, calcite, rock-salt, and some forms of quartz are examples of such, but those that have been thus formed may be readily distinguished. In his valuable paper 'On the Microscopic Character of some Crystals,' Mr. Sorby calls particular attention to certain minute cavities, in even the smallest crystals, which he shows to be the key to the history of the crystal."†

Those who have the opportunity of making for themselves microscopical examination of rocks will find much valuable assistance in the monographs enumerated below (p. 118), there being at the present time no work specially devoted to the subject.

* "Mineralogy." Rutley.

† Microscopical Structure of Rocks. Mello. "Pop. Sc. Review," Jan. 1875.

The microscope, with the apparatus required in its use, is well described in Chap. i. of "Half-hours with the Microscope," by E. Lankester, M.D.; the use of the polariscope in Chap. vii.; and the "preparation and mounting of objects" in an Appendix to the same work.

Chemical Analysis.—Few remarks only will be made on this subject, for (as Mr. Jukes has said*) "proper detailed chemical analysis is not possible, as a rule, to a geologist at work in the field, but he should apply for this assistance not unfrequently." It is the only way of ascertaining the ultimate composition of a rock, but the process is generally a tedious one and requires much experience.

There are some rocks and ores of the metals which may be analysed without much trouble; the method of procedure is plainly given in the little work by Professor Johnston mentioned in the following list, and the subject is more fully treated in Bischoff's "Chemical Geology."

LIST OF BOOKS OF REFERENCE.

MINERALOGY. *Glossary of Mineralogy. Bristow. (Longmans.)*
Mineralogy. Rutley. } *(Murby's*
Mineralogical Tables. Jewsberry. } *series.)*
Manual of Geology. Jukes and Geikie. (Black.)
Geology and Mineralogy. Trimmer. (Parker.)
Ansted's Geology. (Van Voorst.)
Dana's System of Mineralogy. (Trübner and Co.)
Determinative Mineralogy. Brush. (Trübner and Co.)

BLOW-PIPE. *Scheerer and Blandford on the Blowpipe.*
Determination of Minerals by the Blow-pipe. Fuchs. Translated by Danby. (Field and Tuer.)

* *Op. cit.* p. 96.

MICROSCOPE. *On the Microscopic Character of some Crystals. Sorby, Quart. Jour. Geol. Soc. vol. xiv. pp.* 453—500.

The Microscope in Geology. Forbes, Pop. Science Review, Oct. 1867.

On the Microscopical Structure of Rocks. Mello, Pop. Science Review, Jan. 1875.

Communications to the Geological Society. Ward, Rutley, and others. Quart. Jour. Geol. Soc.

Articles by Hull, Allport, and others in the Geological Magazine.

Half-hours with the Microscope. Lankester. (Hardwicke.)

LEVELLING, &c. *Civil Engineering. Rankine. (Griffin and Co.)*

Mathematical Instruments. Heather. (Virtue and Co.)

CHEMICAL ANALYSIS. *Bischoff's Chemical Geology.*

Analysis of Soils, &c. Prof. Johnston. (Blackwood.)

PALÆONTOLOGY. *See page* 146.

PECULIARITIES OF STRUCTURE OBSERVABLE IN CERTAIN ROCKS.

Concretions.—Within the substance of a rock enclosed nodules may frequently be found, of all sizes and varying in shape from flat and angular to perfectly spheroidal. These are "concretions," which sometimes consist of exactly the same material as the rock itself, the form only of the future nodule being indicated by a slight separation of the particles, or by a faint band of colour. Such indications extend not only as a matter of course through many successive laminæ of a bed, but frequently (as do the fully formed concretions) through two or more beds of similar character. In other cases the nodule is more advanced in its formation, a considerable portion of one ingredient of the rock having been by chemical action removed and aggregated around the concretion. Again it may be seen in its complete state when *all* such ingredient has been segregated from the surrounding matrix and from the enclosed nucleus also, in some instances entirely altering their composition and appearance. And at a still later stage concretions may be noticed either wholly or partially decomposed, or they may have been dissolved by water percolating through the mass which has carried away their substance in solution. The cast only then remains, and this also may be modified by similar action and to any extent enlarged, or it may even be again filled with mineral matter by a process of crystallisation.

These concretionary nodules occur in rocks of all ages, and as a rule consist of some substance which has formed a minor ingredient of the enclosing mass. Notable examples are the flints of the Chalk and the iron-stones in Carboniferous clay—and of decomposed concretions, the iron pyrites found in Chalk, many clays and other deposits as a ball of rusty-looking powder.

Concretions may be formed within concretions by further segregation of one particular substance, as, for instance, of sulphide of lead or of zinc in clay-iron ore. As throwing light upon the composition and origin of the rock in which they are found, and on account of their commercial value, concretions are of considerable importance, therefore note should always be made of their occurrence.*

Slickensides.—The walls of a fault or of a joint may

* *Ante*, p. 53.

often be seen somewhat smoothed and finely striated in a direction generally almost vertical to the bedding; this is the result of one portion of the rock sliding down over the other during the progress of the fracture. But a similar appearance is sometimes observable which evidently is not due to friction, as the striæ (or rather fibres) are continued into the substance of the rock; this may be due to "crystallisation in parallel fibres," or to recrystallisation as pseudomorphs after fibrous aragonite. The reality may easily be determined by removing a portion of the striated surface; if the striated structure be apparent within, the striæ are due to crystallisation—if not, to friction; and the fact should then be noted as evidence of some movement of disturbance.

Note on Metamorphic Rocks.—It is generally a difficult matter to decide whether or not a rock owes its present character to the agencies of metamorphism. Rocks originally deposited as sedimentary strata, and having afterwards been altered, behave on a large scale as do the unaltered deposits; *e.g.* "they never, like (eruptive) Granite or Trap, send veins into contiguous formations. In Great Britain those members of the series which approach most nearly to Granite in their composition, as Gneiss, Mica-schist, and Hornblende-schist, are confined to the country north of the rivers Forth and Clyde" (Lyell).

Rounded water-worn grains will be found in most metamorphic rocks, and distinguish them from igneous, when not too compact for the grains to be visible under a lens; and whatever they may at one time have enclosed, they will now be found "wholly devoid of organic remains."

Cabinet Specimens.

For future reference specimens should be taken from a part of the rock observed in a quarry or elsewhere which presents in a typical manner its noteworthy features. They should represent the average colour, show distinctly the crystals, grains, or laminæ, and, if practicable, on one side a weathered surface. Pieces about one and a half inches in length by one inch in width and thickness are of convenient size, but these must be as nearly as possible straight-sided and rectangular. When first detached and chipped into form each specimen must be wrapped in paper with the locality and formation (if possible the very bed) whence derived written thereon. A collection of rocks or fossils, simply as such and without their original locality being known, is for scientific purposes utterly valueless.

After all necessary tests have been applied for determination at home, each specimen should be labelled, or numbered with reference to a list—the label or reference setting forth the kind of rock, the formation (or bed) from which it came, and the locality, in this or other convenient form.

Rock. Oolitic Limestone.
Formation. Great Oolite.
Locality. Box Tunnel.

PART IV.

PALÆONTOLOGY.

CHAPTER I.

Introduction—Nature of Fossil Remains—Review of Animal Kingdom—Mode of occurrence of Fossil Remains.

Introduction.—Palæontology may be defined as the knowledge of fossil organisms, and of the laws which regulate their occurrence in the earth's crust; an acquaintance with these is of very great service to the geologist, whether he be concerned with questions of theoretical interest, or considering such as are of more practical importance.

No treatise on geology or geological surveying would be complete without some chapters on palæontology, for it assists the observer in ascertaining the conditions under which any bed or series of beds were deposited, and in deciding many questions regarding their age and mode of formation which would otherwise remain obscure or unknown.

As a preliminary to such investigations, it is of course necessary that the palæontologist should be well acquainted with the structure and habits of the various tribes, genera, and species now existing upon the globe,

* The first three Chapters of Palæontology are from the pen of Mr. A. J. Jukes Browne, B.A., F.G.S., of H.M. Geological Survey.

especially such as are most nearly allied to those occurring in the fossil state. When in the possession of such knowledge, a study of the fossil contents of a bed, presuming them to exist in sufficient abundance, tells him at once whether the formation was marine, estuarine, lacustrine, or terrestrial; in the three former cases the fossils will be for the most part remains of invertebrate aquatic animals, and an examination of the number and forms of these will greatly help him to form an opinion as to whether the rate of deposition was slow or rapid, whether the water was deep or shallow, near shore or far from land.

Finally, an acquaintance with the different faunas and floras, which have at different times inhabited the world and formed part of the general succession of life upon the earth, enables the palæontologist to estimate the relative age of any particular group of fossils, and to assign them to their probable place in the geological series. In the absence of organic remains, indeed, there is often only slight evidence towards the solution of such problems, and, except where the relative position and lithological characters of the rocks are very marked, the fossil evidence is of great use in confirming the conclusions derived from an examination of the strata themselves.

The important doctrine that strata may be identified by their fossil contents was first taught by William Smith, and is thus expressed in a sentence extracted from his "Stratigraphical System:" "Organised fossils are to the naturalist as coins to the antiquary; they are the antiquities of the earth, and very distinctly shew its gradual regular formation with the various changes of inhabitants in the watery element."

Now obviously before we can apply this highly useful doctrine to any particular series of beds, and before we consider any further the ultimate use of such investigations, we must become thoroughly conversant with the nature and mode of occurrence of fossils, and with the ways and means of collecting them. The following observations therefore are offered for the purpose of giving some information on these several points, and of shewing how, by a regular and systematic method of procedure, the field-geologist may furnish properly-collected materials for subsequent study, whether he works out such results for himself, or leaves them to be dealt with by a professed palæontologist. But we must here remark, that palæontological results, however carefully and thoroughly worked out, should never be taken as conclusive by themselves, and without being confirmed by the facts or probabilities of stratigraphical evidence, as far as these can be ascertained; it is only in such cases as those of outlying deposits that, in the absence of any such confirmatory evidence, the character of the fauna may be held sufficient to *decide* the questions of relative age or contemporaneity with other distant formations. The geologist therefore should be careful as far as possible to make his palæontological enquiries proceed hand in hand with those regarding the relations of the strata which contain the fossil relics.

Again, he must not only collect the fossils from localities and beds where they happen to exist in an exceptionally good state of preservation, but take care to secure all the specimens he can from every bed in the series, even where these are in an obscure or fragmentary condition. In this way he will obtain knowledge which will lead to a thorough and philosophic description of the rocks composing the area upon which he is engaged, and will enable him to understand aright its physical, stratigraphical, and palæontological peculiarities.

I. Nature of Fossil Remains.

Fossils have been defined as "organic remains buried in the earth," the operations of natural causes being of course understood, and no limitation as to the subsequent lapse of time nor any reference to their present state being allowed to enter into the definition; since, as Mr. Jukes has well observed, "any accumulation of shells, or bones, or plants, which could be said to be *buried in the earth* by any other than human agency, even if that burial took place last year, would be well worth the attention of the palæontologist." Our first enquiry must have reference to the nature of these remains, the particular organic forms which are likely to occur fossil, and the various states of preservation in which they are severally and collectively found.

It is not every buried organism that leaves behind it a permanent record of its previous existence, and only those animals which contain a bony skeleton, or are enclosed in a hard shell or test, can as a rule become definitely fossilized; while plants and those animals which do not possess any such hard structures are rarely found, except in the form of impressions or tracks on the surface of beds—the peculiar mineralization which woody matter undergoes being of course an exception to this statement.

Again, the nature of the remains or records of past existences will naturally vary according to the class of animals by which they were originated, and setting plants aside for the present, it will be worth while reviewing the animal kingdom for the purpose of seeing what groups are likely to be met with at all in the fossil state, and which of them so occur in greatest frequency and abundance.

REVIEW OF ANIMAL KINGDOM.

Vertebrata.

Mammalia—occur rarely, except in recent fluviatile deposits, and then generally in the shape of separate bones and teeth.

Birds—from their aerial existence, are still rarer as fossils, bones seldom occurring; but their footprints and even impressions of their feathers are known.

Reptilia.—Remains of all recent and extinct orders, except the Ophidia and Lacertilia, are tolerably abundant; their bones, teeth, scutes, and in some cases their eggs and coprolites being found.

Amphibia—are represented in certain formations by their bones and teeth, as well as their tracks or footprints.

Pisces.—The bones, teeth, and scales of fishes are common in almost every formation, from the Silurian upwards.

INVERTEBRATA.

Mollusca.—Remains of all those classes possessing internal or external shells are very abundant; the Tunicates being soft-bodied are alone unrepresented.

Annulosa.—Of *Insects,* the skins, limbs, and wings are occasionally found; of *Myriapoda* and *Arachinda* remains are very rare; of *Crustacea,* the limbs and carapaces are found in abundance, and from the earliest times.

The *Annelids* are only known by the shells of Tubicola, and by the tracks and burrows of other orders.

Annuloida.—*Echinoderms* are frequent fossils, leaving remains of their tests, stems, arms, or spines.

Scolecida, having no hard parts, are quite unknown.

Cœlenterata.—The *Actinozoa* present abundant remains of their hard skeletons or corals; but the *Hydrozoa,* being mostly soft-bodied, have left few traces.

Protozoa—are chiefly represented by the spicules of Sponge and the minute shells or tests of Foraminifera.

Since the majority of rocks composing the crust of the earth are of aqueous and principally marine origin, we should naturally expect the fossils which they contain to be the remains of aquatic and principally marine beings; this at once accounts for the preponderance of such forms in the above list as are commonly met with in the fossil state.

Thus, in the Vertebrata, the remains of mammals and birds are among the rarest of geological relics, even in beds of littoral or terrestrial origin, save those of very recent date; on the other hand, marine reptiles and fishes are found in almost all the later fossiliferous deposits, their vertebræ, scales, and teeth being occasionally very abundant; they seldom occur, however, in anything like a perfect condition, except in certain strata which have been formed quietly and rapidly enough to envelop them before dismemberment.

Among the Invertebrates the group that is by far the most useful and important to geologists is that of the Mollusca; they usually present us with a complete enveloping shell or test, instead of the fragmentary remains which are generally left to represent the individuals of the Vertebrate classes; and from their constant occurrence in almost every fossiliferous bed they form an excellent standard of reference in considering questions of relative age and position. William Smith has happily likened fossil organisms to coins and antiquities, and the remains of mollusca are to geologists as the numismatic relics of a kingdom which has lasted from the earliest dawn of life upon the earth down to the present day.

Corals and Echinoderms occasionally occur in considerable profusion, and sometimes form great thicknesses of rock. Foraminifera too are of very general distribution, but from their small size and low place in the animal scale, they are not of much practical use to the geologist. Crustacea are of more limited occurrence, most abundant in beds of littoral origin, but rare in sandy strata, and often absent in deep-sea deposits.

II. *Mode of Occurrence of Fossil Remains: Petrifaction.*—When organisms have once become buried in deposits formed at the bottoms of seas, lakes, or rivers, and their soft parts have decayed away, it might be thought that the hard portions would remain then unchanged, until disentombed by the hands of the geological excavator. This, however, is not the case; on the contrary, they have in most instances been subjected either to contemporaneous or subsequent mineralizing processes, by means of which they are more or less hardened and petrified.

It often happens that the animal matter in decomposing has given rise to various chemical reactions, which have resulted in the formation of fresh mineral matter and its concentration round the body of the decaying organism; in such a case the animal becomes included within the mass, and its harder parts, being usually preserved from further change, are disclosed on the splitting open of the nodule or concretion which is thus formed.

Where, however, this does not take place, and the fossil is simply enclosed in the ordinary matrix of the rock, it is always liable to more or less subsequent alteration; in pure clays this change is generally very slight, simply consisting in the complete abstraction of the organic constituents, and if the test or skeleton is siliceous little alteration is effected; but in other rocks, and where the shell or test is of a calcareous nature, it frequently happens that the whole of it has disappeared, and has either been replaced by other mineral matter, or else the space which the shell once occupied is left open, and nothing remains but the external impression and the internal cast formed of the material which filled up the empty shell.

Fossils therefore may be considered as occurring chiefly in four different states or conditions, viz.:

1. As unchanged shells or tests.
2. As replaced shells or "*pseudomorphs.*"
3. As internal casts.
4. As external impressions.

1. *Unchanged Fossils.*—These may at once be distinguished from those that have been replaced by their mode of disintegration; they peel off in concentric layers, and disclose the original lamellar or cellular structure of the shell. Crag fossils and those of many sands and clays occur in this state of preservation, and are quite unaltered save by the abstraction of all the organic matter, for which reason they fall to pieces very easily.

2. *Replaced Fossils.*—Those that have undergone replacement split with a definite angular cleavage quite through the shell. The fossils of the chalk, for instance, though still calcareous, split in this way, and the bivalves have moreover entirely lost their internal nacreous layer, so that no traces of the hinge or muscular impressions are, as a rule, visible. In other limestones this calcitic cleavage is still more marked, rhombohedral fragments may be chipped out of the thicker shells or from the tests and spines of Echinoderms, while inside perfect crystals may often be found. This is the case even with the fossils of some argillaceous beds, and every one is familiar with Lias Ammonites which have been cut and polished to show the chambers full of calcite

spar; in other cases the replacing material is Iron-pyrites, Selenite, or Silica.

The agency which produces such changes is simply water charged with carbonic acid and holding in solution the various mineral substances above mentioned; this acidulated water, percolating through the rocks, slowly and gradually dissolves away the carbonate of lime composing the shell, and in many cases replaces it particle by particle with the other mineral which it happens to contain in solution, and which is thus exchanged for the carbonate of lime; in other cases the material of the shell may have been entirely removed without any concomitant replacement, the calcite, silica, or other mineral having been subsequently introduced into the vacant space thus left, and filling it up as it would any other cavity in the rock.

But to explain the change of structure in some calcareous shells which are not wholly replaced, it seems necessary to suppose that the percolating water contained a saturated solution of carbonate of lime, some of which crystallized out in the cellular interspaces of the shell, binding the whole and imparting to it a crystalline structure, just as the sand of Montmartre, being infiltrated by carbonate of lime, is gathered together by crystalline action into rhombohedral prisms, taking the form of calcite crystals.

3 and 4. *Casts and Impressions.*—The internal cast and external impression may be considered together, as they nearly always exist, whether the shell be unaltered, replaced, or removed; they are of course very much better seen and realized in the latter case, when the cast is loose or nearly so, and may be taken out of the cavity,

thus revealing the impression or reversed facsimile of the external form of the organism that once filled the empty space.

Suppose, for instance, we are dealing with the remains of a bivalve shell, such as a Trigonia in the figure,

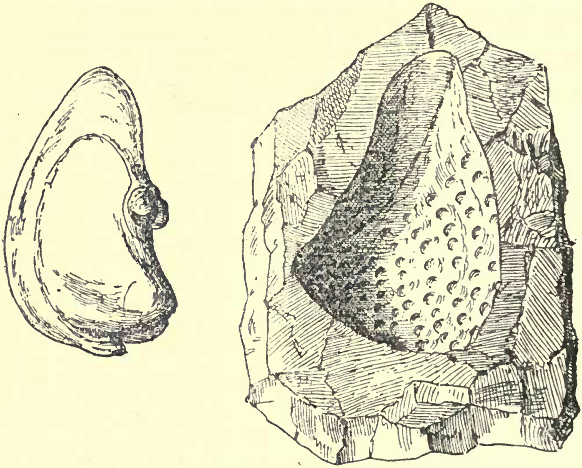


Fig. 20a. Trigonia clavellata, Kimmeridge Clay. Cast and Impression.

we find that the cast exhibits two raised ledges occupying the position of the muscular impressions, connected by a slightly raised ridge, corresponding to the pallial line which marks the attachment of the animal's mantle; the interspaces between the teeth will also appear, and sometimes concentric or radiating ridges answering to those of the shell itself. In the same way the internal structure of any hollow body, whether coral, univalve shell, or echinoderm, is faithfully represented by its cast, and where opportunities for comparison exist, its genus and even its species may in many cases be ascertained.

While the internal cast thus exhibits in relief all the markings and irregularities which existed on the inner surface of the shell or test, the external cast or impression is indented by all the markings which ornamented its outer surface. Where the shell is absent, therefore, and we wish to gain an idea of its appearance in relief, we can effect this by taking an artificial cast from the external impression, and thus obtain an accurate representation of the pre-existing shell. Occasionally even, but very rarely, this is effected by natural means, and we then get an internal cast, showing all the characters of the external shell; this seems to be only produced in soft sandy marls or muds, where a thin shell having been dissolved and never replaced, the impression of its exterior has been gradually and equally squeezed on to the still soft mud inside; this, on the desiccation and consolidation of the rock, would present every appearance of the original fossil, though the closest examination would reveal no traces of shell structure; instances are found in some fossils from the chalk marl and from the Bracklesham beds in the Isle of Wight.

CHAPTER II.

PALÆONTOLOGY (*continued*).

Method of Collecting Fossils—Examples.

I. *Method of Collecting Fossils.*—In Part II. p. 53, the mode of procedure in examining any natural or artificial section, whether cliff, cutting, pit, or quarry, was described, and it was pointed out that notes should be taken of the nature and contents of the rocks therein exposed; also that these open cuttings and sections must be closely searched for the fossil remains which the several beds may contain.

Although it is not often that every separate bed or layer contains definite remains of fossil organisms, yet there are few without some traces of animal life, and even in a limited series of strata there is usually one at least which contains them in greater or less abundance. These remains must be diligently collected, whether they be large or small, common or rare, in a good or bad state of preservation; for this object certain tools and apparatus are necessary, and these are different according to the nature of the rocks that are likely to be met with in the area surveyed. For instance, among hard rocks, or even those of moderate compactness, a hammer and chisel will of course be required, and indeed the geologist should rarely be without the hammer and pick in some form or other; on the other hand, where only soft clays or marly sands are to be explored, a good strong clasp-knife will be found a more effective instrument for extracting the fossils that they may contain.

Large and strong specimens may be simply wrapped in paper, with a note of the bed and locality written on it; while the smaller and more delicate specimens are best stowed in small boxes, with wool or soft paper,—common chip-boxes are perhaps as serviceable as any for this purpose.

All this apparatus may be carried in a bag slung across the shoulders, but where large and heavy "takes" are expected, and especially among the older rocks, a fisherman's basket will be found admirably suited for such service, since in this the various fossils and rock-fragments can be firmly and securely packed as they are collected, thus preventing their tendency to shake about and scratch one another during further exploration.

When fossils are extracted from hard rocks, and are detached in lumps or fragments of considerable size, they should only be reduced and roughly trimmed according to the dimensions of the enclosed organism, leaving further manipulation until the specimen arrives at its destination, whether this be in a private or public collection, for the final chipping and trimming often requires to be done carefully and leisurely, so as not to break or damage the fossil. A deft and skilful handling of the hammer and chisel is indeed only to be attained by much practice, and the ultimate development of a specimen is always a more or less delicate operation, from which it does not always escape uninjured.

In chiselling anything out of a soft rock like chalk care should be taken to direct the chisel away from the fossil, and to extract a larger lump than may at first sight seem necessary, otherwise the rock may flake up and destroy the specimen; when safely extracted, it should then be slightly trimmed, wrapped in plenty of paper, and stowed in the bag or basket.

With still softer rocks, such as shales, clays, and clayey sands, the specimens can at once be reduced to the proper size and shape by means of the knife; and then, if carefully conveyed, will need little further attention, unless some preservative, such as gum or gelatine, be required for their ultimate conservation.

For fossils that are found in loose sands, whether freshwater or marine, and that may be extracted whole and free from the matrix, more care is needed; they are almost always in a tender and perishable condition, and should be immediately packed in boxes with wool or bran.

> *Note.*—Where these materials are unattainable, or have been forgotten, clean sand from the shore or pit itself may be used as a fair substitute, though it has, of course, the disadvantage of being much heavier.

Ordinary chip-boxes have already been mentioned as useful for this purpose, and are easily stowed and carried, but they are sometimes hardly strong enough, and such small wooden cases as those in which baking-powder is sometimes sold will be found serviceable.

We have hitherto spoken of the fossil remains which are actually included in the matrix of the bed or stratum, and were deposited there in most cases after the death of the animal, and during the accumulation or deposition of the materials which form the matrix. But since every bed or layer of a sedimentary rock once formed the bottom of a river, lake, or sea, we should naturally expect to find some fossils resting on their surface more or less in the position of growth, as well as the tracks or marks of animals which also come under the category of fossils. These, of course, will be seen by separating the layers which compose the series of strata under examination, or may be found on the surface of beds already exposed. The Dudley slabs are good examples of this, and other instances are often found in the shales and limestones of the Oolitic series.

Nodule beds, bone beds, and layers of flint or chert all also mark pauses in deposition of greater or less length, and are often very rich in organic remains. Indeed, the nodular concretionary masses which usually characterize such beds owe their origin mainly to the presence of organic matter, the decomposition of which has resulted in their production. Those containing phosphate of lime or other materials of commercial value are often extensively worked by pits or trenches; admirable opportunities are thus afforded for collecting the fauna they exhibit, both in the pits themselves and among the washed heaps of these products.*

For the same reason all concretionary nodules, whether accumulated in layers or not, should always be examined and broken open, since many excellent fossils are frequently obtained therefrom; such as those enclosed in the ironstone nodules of the Carboniferous series, and in the *Septariæ* of many clays.

II. *Examples.*—In illustration of the previous remarks let us refer to the diagrams, figs. 5, 6, 7, and 8, and the descriptions contained in Parts I. and II. of this work.

(*a.*) It will be remembered that the first quarry we entered, in imagination, was a sand-pit near the church, in fig. 5; in the light grey sand at the bottom of this pit a few fossils were noticed; these should be extracted from the matrix or detached with portions of the rock, some being in the state of buff-coloured casts, others retaining their shelly covering, some are fragmentary, others in a fairly perfect state. After a diligent search among these friable beds we collect some twenty or thirty specimens, which we recognise to be various species of Ammonites, Terebratula, Rhynconella, Ostrea, and Plicatula, &c., &c. These are carefully

* The so-called "coprolite-pits" in the neighbourhood of Cambridge form an example of this mode of occurrence, and the consequent method of collection.

wrapped in paper, or stowed in chip-boxes, according to their size and fragility. The small sponge-like nodules are also taken for future examination with the lens and microscope.

In the marly or sandy chalk above we notice that but few fossil remains occur; we extract, however, one or two Belemnites, a few obscure Terebratulæ, and fragments of Inoceramus shell. These, though apparently worthless and not easily identified, should nevertheless be kept, and their occurrence noted, since in other pits on the same horizon better specimens may be obtained with which these may be compared.

If we are not able to name at once the species which have thus been collected, we can leave spaces in the note-book and fill in the names after consulting palæontological authorities.

(*b*.) Passing down the road to the brickyard or gault-pit, which was next examined, and searching over the clay which is thrown aside, as well as in the vertical cutting of the pit itself, we find that fossils are not uncommon. They mostly retain their shells or tests in very fair condition, and only contain the dark mud or gault in which they lie; some, however, which we observe to occur mainly along one definite line or horizon, are filled with iron pyrites or with impure phosphate of lime, many of these being merely casts in one or other of the above minerals.

From the workmen we also buy what fossils they have found and laid aside when digging the clay in the winter; these are generally only the finer and larger species, while for the smaller and less conspicuous fossils we must search the pit ourselves. We may note the following as among those obtained, reserving the more doubtful forms for future identification:

Ammonites varicosus.	Solarium ornatum.
——— splendens.	Plicatula pectenoides.
——— rostratus.	Avicula gryphæoides.
Hamites sp.?	Inoceramus sulcatus.
Belemnites attenuatus.	Nucula pectinata.
Rostellaria sp.?	Pentacrinus Fittoni.

We also secure a few of the different forms of the phosphate nodules from the seam or band in which they were noticed to occur.

It is not always, however, that a clay-pit is so fossiliferous as that described above; indeed, if the workmen happen not to have any specimens on hand, as is often the case in summer-time, little else may be obtained from such gault-pits than a few Ammonites, Belemnites, Plicatulæ, and phosphate nodules, though a regular seam of the last is tolerably sure to afford a more or less abundant and well-preserved fauna.

(*c.*) At the well we are not likely to obtain any fossils unless some of the clay which was extracted still remains near the mouth, or the well-sinkers happen to have kept any specimens from the beds passed through.

(*d.*) The chalk-pit must be examined carefully, for it is not so easy to detect fossils in the upper chalk as it is in most other secondary rocks; the remains are nearly of the same colour as the rock itself, and this is of such dazzling whiteness that looking closely at it in bright sunshine is very trying to the eyes; however, we must first betake ourselves to a shady part, and get gradually accustomed to the glare.

We may begin by turning our attention to the flint-bands which have been remarked upon before, and by examining the nodules in place, and the heaps of those which we see by their white exterior to have been in place, we soon collect several Echinoderms: *Ananchytes*, *Micraster*, and the spines of *Cidaris*, together with a few specimens of *Inoceramus* and *Spondylus*, all imbedded in the flint. These must be trimmed as well as possible, although flint is very intractable, and just as likely to split through the fossil as along the plane intended. Flint is perhaps best manipulated by holding the lump in the left hand, and chipping it by well-aimed blows of the hammer, each one directed away from the enclosed fossil.

The flints having been well looked over, we turn to the beds of chalk themselves, and when our eyes become used to its appearance we soon extract, by means of hammer and chisel, specimens of the same species just found, with the addition, perhaps, of some smaller fossils, such as *Magas pumilus*, *Terebratula carnea*, *Rhynconella octoplicata*, *Crinoid stems*, and plates of *Marsupites Milleri*.

We examine also the tests of the large and smooth Echinoderms, such as *Ananchytes* and *Galerites*, which are often the resting-places of *Crania*, *Plicatula*, and the minute *Thecidium Wetherellii*, as well as various species of elegant *Polyzoa* and *Serpulæ*. A chalk-pit is very frequently a lime-kiln also, and the men at work almost invariably preserve some of the more striking fossils they meet with in quarrying the rock; these, therefore, may generally be obtained "for a consideration."

(*e* and *f*.) In the loam at the brickyard few fossils are likely to be found, except perhaps some fragments of

Ostrea Bellovacina among the green-coated flints at the base. In the sands above we find only a few specimens of *Ostrea* and *Cyrena cordata,* which are readily separated from the matrix, but in a very friable condition, so that careful handling and packing are required; but these afford sufficient evidence (in addition to that of stratigraphical position) to identify the beds as belonging to the Woolwich and Reading group of the Eocene series.

An example of surveying among the older rocks is also given in fig. 21, and our palæontological explorations are here even more useful and necessary to confirm the conclusions drawn from the stratigraphical evidence.

In the sandstone quarry, No. 2, it will be noted that some fragments of a substance resembling wood were found; these, when subsequently sliced and subjected to a microscopic examination, show the characteristic structure of coniferous wood, but at the time of collecting they could only be entered as "fragments of wood, coniferous ?" In the shales forming the uppermost part of the quarried cliff fish scales were noticed to be tolerably abundant, and portions of the crushed skeletons may also be detected, belonging to the Lepidostean fish *Palæoniscus comptus,* which is characteristic of the Permian marl-slate; we are sure, therefore, that the shales belong to this division of the series.

In the limestone quarry to the south-west fossils are much more abundant, though confined to the grey limestone in the upper part of the quarry. Some parts of this may not be accessible, but numerous blocks of it are lying about, and we find that the fossils are readily extracted from the rock; at the same time they are tolerably hard and strong, and need little care beyond the protective power of old newspapers.

The character of the rock and its stratigraphical position are almost sufficient to prove that it belongs to the lower part of the Magnesian limestone, and the fossils abundantly confirm this surmise, being those which are characteristic of the second member of this series, the "fossiliferous limestone" of *Prof. King.* Among them are, *Fenestella retiformis, Producta horrida, Camarophoria crumena, Monotis speluncaria, Schizodus obscurus,* and *Bakevellia antiqua.*

Round the mouth of the coal-mine there are scattered portions of the various measures passed through in sinking the shaft; among the fragments of sandstone and fireclay thus brought to light we may find remains of *Calamites, Stigmaria,* and *Sigillaria;* in the shales and shaly sandstones we detect impressions of *Lepidodendron* stems, together with the broken fronds of *Neuropteris, Sphenopteris,* and other ferns, all black and carbonized.

In the dark shales also Unio-like shells occur, belonging to the genera *Anthracosia* and *Anthracoptera,* but they are often more or less crushed; the best specimens are obtained from the dark-grey ironstone nodules which are scattered about, and which we ascertain to have been derived from the shales below the first coal-seam (see section on p. 212). Besides the bivalve shells, these nodules contain beautiful fragments of fern leaves, as well as *Lepidostrobi,* or the cones of the *Lepidodendron,* and sometimes the scales or coprolites of fish; it was indeed the decomposition of the animal or vegetable matter that determined their formation.

The above-mentioned organic remains stamp the beds containing them as being of terrestrial, freshwater, or at most estuarine origin; but amongst the debris we notice slabs and pieces of impure limestone which yield specimens of more marine forms of life, such as *Goniatites Listeri* and *Aviculopecten papyraceus*, and possibly a closer view may disclose the presence of smaller organisms, such as the minute annelid, *Microconchus carbonarius*. We subsequently ascertain that the fragments disclosing those remains have come from the bed marked limestone in the section on p. 212.

Now, descending the pit, we explore some of the main passages or gate-roads, under the guidance of the foreman, or "butty-collier;" in some places we find the roof above us to be crowded with splendid impressions of ferns and other plants, the shales immediately above the coal being often extremely rich in such remains; and we thence obtain better and more perfect specimens than we could at the mouth of the pit, with the additional advantage of knowing the precise horizon or band in which they occur.

From the information thus obtained we learn that frequent oscillations of level took place in the area where these beds were deposited; for instance, the shales above the third coal-seam mark a slight depression of the low-lying land on which the vegetation grew, and its temporary submergence under the waves of the neighbouring lake or estuary; after a slight upheaval which allowed the growth of the thin coal, it again sank under the water and was covered up by the overlying shales, the depression reaching its farthest extent when the impure marine limestones were formed;

but that this depth was not very great, is evidenced by their muddy and shaly character, caused by the admixture of sediment brought down from higher land. A reverse movement soon set in, the area slowly rose again and the shales with ironstone nodules were accumulated; finally, the bay or estuary must have been silted up by the deposition of such sediment and again became a land surface at the time when the plants forming the uppermost coal-seam grew and flourished in their rank luxuriance.

CHAPTER III.

Preservation, Naming, and Arrangement of Fossils—Value of Palæontological Evidence—Evidence of Physical Conditions.

Preservation of Fossils.—Having collected and brought away our fossils in the manner described in the preceding pages, it behoves us to say a few words regarding their further treatment and mode of preservation.

We have already recommended that a note of the locality and the bed from which they were obtained should be written on the paper or box in which they are enclosed, and if this is done at the time, they may be deposited at headquarters and left till winter or wet weather affords leisure for dealing with them.

They should then be taken out, carefully inspected and sorted, only the very worthless duplicates from *the same bed and place* being put on one side; attention must then be paid to the more delicate specimens, such as those obtained from the loam-pit in fig. 8, from Crag-sands or from River-gravels; these will require thorough soaking in a solution of gum or gelatine (the latter being of such strength as just to set on cooling). Specimens that have been cut out of soft sandy clays will also be benefited by such soaking, since they are apt to crack and crumble in drying; such treatment may in many cases be deferred until the specimens have arrived at their ultimate destination, wherever that may be.

Chalk fossils and those that have been obtained from any similar porous limestone along the *sea-shore* should be soaked in fresh water for several weeks, the water being changed at least once a week; this is the only way we know of to prevent the efflorescence of the salt in such cases, and the consequent splitting up of fossils which have cost time and pains to extract. We have now in our collection Chalk Echinoderms and other fossils which were thus treated seven or eight years ago, only one or two of them having "*gone*," probably in consequence of insufficient soaking.

Naming and Nomenclature.—Having thus prepared our fossils for their final packing on the completion of the geological survey of the district, every specimen ought to be numbered, and the numbers entered in a special book, the name, locality, and " location " of each being entered opposite every one. With regard to the naming, it will probably be impossible to name all, without reference to other authorities than are then at command; in these cases the numbers will show the specimens which remain for future identification.

We will now suppose that the whole collection has arrived at its ultimate resting-place, whether this be a private or public museum.

In the latter case further trouble is probably taken off our hands by the staff of palæontologists and assistants, and from them we obtain a full account of the fossils obtained in the several beds and localities of the district explored.

It may be well, however, to give a few hints for the furtherance of private work in this department, and firstly to give a list of the principal books of reference necessary for the identification of fossils,—those for England and France alone being mentioned.

The Publications of the Palæontographical Society, in which 4000 species of British fossils have already been figured and described.

Decades of the Geological Survey of England.

McCoy's *Palæozoic Fossils,* published by Prof. Sedgwick.

Sowerby's *Mineral Conchology.*

Mantell's *Medals of Creation.*

Owen's *Palæontology* and Nicholson's *Manual of Palæontology* will also be found useful.

Baily's *Figures of Characteristic British Fossils.* (Van Voorst.)

D'Orbigny's *Paléontologie Française.*

Pictet's *Matériaux pour la Paléontologie Suisse.*

For the fossils of particular formations, such works as Dixon's "Geology of Sussex," Murchison's "Siluria," Ramsay's "North Wales," and other Survey Memoirs must be consulted, as well as papers in the Journals and Transactions of the Geological Societies of London and Paris.

In identifying the various species by means of these volumes we shall probably find some which are apparently intermediate in their characters between two nearly allied forms, and are thus difficult of certain determination, since they might belong to either of the figured species; others, again, may vary more or less from the particular type which happens to be figured. Now it is often the practice in such cases to put these aside for duplicates, or even to throw them away altogether, only inserting in the collection what are termed "typical specimens;" but this mode of procedure is reprehensible in the highest degree, since it tends to confirm the old superstition that species are definite abstractions, and to draw hard and fast lines between cognate forms which are unnatural and nonexistent in reality.

These forms ought, on the contrary, to be placed with the species to which they are allied, and to be labelled as a variety of that which they most closely resemble. Had this always been done in private and public collections, we should now be in possession of many more facts regarding the life-history of such forms than we have knowledge of at the present time.*

Besides these intermediate and somewhat indeterminable forms, we may also discover some that do not

* It will frequently be found that such intermediate forms have been collected from intermediate beds, one of the allied species being mainly found above, and the other below, the horizon in which such middle varieties occur. It is unnecessary to point out the bearing of this on Darwin's Theory of Evolution (by descent with modification); every one who has read the "Origin of Species" will understand it, and every one who has not read that work should do so without delay.

appear to be figured or described at all in any of the books we can consult; these should be put on one side, and if possible shown to some palæontologist who makes a special study of the groups to which they severally belong: should they prove to be entirely new species or definite varieties, they may be described as such when an account of the district comes to be written.

The whole subject of scientific nomenclature is at present in confusion; but, without going into the matter, we may briefly point out the main causes of this unsatisfactory state of things, and suggest some means of remedy.

In the first place, the illusory ideas regarding the definiteness of species have greatly contributed to it, for different authorities have had different estimates of specific differences, and many so-called species are after all mere arbitrary creations of individual opinion.

Secondly, there exists the great desire of finding something new to Science, which too often takes the form of "species-*making*" instead of *discovery*.

Thirdly, the difficulty in many cases of finding out whether a species has been previously described, either by British or foreign writers, has operated in the same direction. All, in fact, are fruitful causes of the multiplication of synonyms.

The first of them opens a difficult question, for a name is undoubtedly required even for varieties, if they are tolerably definite and constant; the only way out of the difficulty appears to lie in the more general use of subgeneric titles, grouping species together under their respective genera, and using in fact a *trinomial* instead of a *binomial* nomenclature.

The only cure for the second tendency is to read Darwin's "Origin of Species," and persons who will not do that may be given up as hopeless.

The last and most direct cause of the production of synonyms is only to be avoided by greater industry and carefulness, and by making fuller acquaintance with the work done in foreign countries; in this endeavour palæontologists will be greatly assisted by the annual publication of the "Geological Record," their only regret probably being that it had not an earlier commencement.

Arrangement of Collections.—We have often been questioned as to the best mode of displaying and arranging fossils. With regard to the mode of arrangement, whether according to their place in the succession of life or in the succession of strata, there can be only one answer: the latter is always preferable for *geological purposes*, however much the former may commend itself to the pure biologist.

Nevertheless, in collections of any size, it is always possible to have zoological arrangement, by placing together those of the same natural group and class, and pursuing the same order of classes throughout all the formations.

Secondly, regarding the method of displaying the fossils themselves: in museums, where the collections are supposed to be perfected, and to remain as arranged for many years, the specimens are generally fastened down on tablets; but in private collections, which are used for constant reference, and to which frequent additions are made, such a plan is attended with many disadvantages. The simpler and better way is to place them in small card-board trays, made of multiple sizes like the tablets; every fossil may then be fully examined and handled, while the labour and time expended in the process of gumming them down is thereby avoided, and the additional advantage of space is gained at the same time. The names may be written on separate pieces of card-board, and either placed loose in the tray or pinned on to its edge.

Value of Palæontological Evidence.—Having now explained the method in which the fauna and flora of a district should be collected and worked out, we are in a position to estimate the full importance and usefulness of the information thus obtained, and the light which is often thrown by this knowledge upon such questions as the relative and comparative age of beds, and the physical conditions under which they were deposited.

The insight afforded by Palæontology into these subjects was briefly pointed out at the commencement of Chapter i., but may now be more fully explained.

First, as regards the various conditions under which rocks may have been formed, we find that our knowledge is chiefly derived from the evidence furnished by the organic remains they contain. It is clear that the terrestrial, fluviatile, lacustrine, estuarine, or marine origin of the fossils may generally be ascertained by a comparison with the habits of the living species belonging to the same or nearly allied genera.

But we may go farther than this, and even obtain some idea of the probable climate of past periods; when we find in certain beds the bones of crocodiles, snakes, and turtles, together with palm-fruits and remains of other plants which now live only in tropical regions, we are forced to believe that the climate of the British islands must then have had a more tropical character. Again, when in more recent deposits we discover remains of the reindeer, musk-ox, and mammoth, and in other beds of the same age certain species of mollusca which now only inhabit the seas of more northern regions, we have good evidence for concluding that the climate of Britain was then very much colder than it is at present.

From a consideration of the character and abundance of the fossil remains we may sometimes gain an idea of the time that elapsed during their accumulation. The formation of a bed of limestone crowded with organisms of various kinds, many of the corals and crinoids being still in their upright position of growth and surrounded by the broken debris of others, together with the shells of numerous species of mollusca,—the formation of such a bed must have occupied a long series of years.

A bed of sand or sandstone will, on the other hand, enclose a very different class of relics, if it contain any at all,—bivalve shells, mostly with separated valves, the waterworn fragments of some corals and gasteropods, and possibly a few drifted bones of some terrestrial animal, may be found; such remains indicate the rapid accumulation of the materials composing the stratum, which indeed, although of the same thickness, may only have occupied in its formation as many weeks as the bed of limestone did years.

Other facts are also elicited by such a comparison; for many of the fossils occurring in the limestone belong to genera which exist only in deep water, and the very mode in which they occur shows that the water above was still and quiet; we conclude, therefore, that it was deposited at the bottom of a deep and quiet sea.

In the sandstone, on the contrary, the presence of terrestrial remains and the drifted and waterworn condition of the other fossils found therein plainly indicate their connection with a shallow sea, the action of currents, and the neighbourhood of land.

Again, such indications as sun-cracks and the impressions of rain-drops tell us of parching heat, of passing showers, and even show us the direction from which the wind blew in those old days of the earth's history.

We will turn now from such evidence of the surrounding conditions at the time when the beds were formed, and approach the more difficult questions connected with the comparative age of the different beds which are found in different localities, and make up the crust of the earth.

It has been observed, that every group of strata in the geological series, and frequently even the minor beds composing the several formations, have each their own peculiar assemblage of fossils; it often happens that a particular species, or an assemblage of species, are only found in a particular bed or stratum, or if found at all elsewhere it is so rarely in comparison with their abundance in this particular stratum, that they still merit the name of *characteristic species.* Still more is it the case when a considerable formation or group of beds is examined, for these invariably contain a greater or less number of species which are absolutely peculiar to the group, and are never found in the rocks above or below.

This generalization—first made by the "Father of English Geology," William Smith—leads directly to the doctrine that "strata may be identified by fossils," for if these groups of characteristic species have been changing throughout all time, and were different in every geological period, we see at once that the relative age and position of beds may be known from their embedded fossils.

To take a simple instance: *Ammonite* shells and the bones of an *Ichthyosaurus* have been discovered in some of the Arctic Islands, and we at once conclude that the rocks containing them belong to some member of the Secondary system; moreover, we guess that they belong to the Jurassic formation, since the Ammonite more resembles an Oolitic form than any known in Cretaceous rocks.

Another more detailed instance may be given: It is known that there are among the Upper Silurian rocks three distinct beds of limestone; where these occur in a disturbed and faulted district, we might discover a quarry in limestone, forming part of an area which had been faulted up or down, and thus separated from beds with which it was originally continuous. In such a case the stratigraphical evidence might be very obscure, but the palæontological evidence would at once decide the matter, for on finding among the fossils which had been collected from the limestone specimens of the large Brachiopod, *Pentamerus Knightii*, we should recognize in it a fossil characteristic of the Aymestry limestone, and have little hesitation in referring the beds to that formation; if, on the other hand, we found such forms as *Acervularia luxurians*, *Euomphalus discors*, and

Orthis rustica, we should be sure that the rock belonged to the Wenlock group, and was the second of the three limestones above mentioned.

As the application of fossil evidence has often a very practical bearing, we may take even another instance from the history of coal-mining: it has frequently happened that much labour and money have been fruitlessly wasted in the search for coal, which would have been prevented by the slightest acquaintance with the laws of palæontology, the beds through which shafts have been sunk yielding fossils, not of the species mentioned on p. 142, but such as are characteristic of Silurian shales or Kimmeridge clay.

The late Mr. J. B. Jukes says: "I have known, even in the rich coal district of South Staffordshire, shafts continued down below the Coal-measures, deep into the Silurian shales, with crowds of fossils brought up in every bucket, and the sinker still expecting to find coal in beds below those Silurian fossils. I have known deep and expensive shafts sunk in beds too far above the coal-measures for their ever being reached, and similar expensive shafts sunk in black shales and slates in the lower rocks far below the coal-measures, where a pit might be sunk to the centre of the earth without ever meeting with coal. Nor are these fruitless enterprises a thing of the past. They are still going on in spite of the silent warnings of the fossils in the rocks around, and in spite of the loudly-expressed warnings of the geologists, who understand them, but who are supposed still to be vain theorists, and not to know so much as the '*practical man.*' Within my own experience large sums of money have been absolutely thrown away, which would have been saved by the slightest acquaintance with palæontology."*

The mode of procedure, however, indicated in the above examples necessarily presupposes that the stratigraphical succession has first been established in some other locality where the relative position of the beds is clearly seen, so that there can be no doubt about the comparative age of the faunas they contain; in other words, the successional order of the faunas must first be clearly ascertained before a knowledge of them can assist in elucidation of faulted or outlying districts; while these conditions have not been fulfilled palæontological reasoning is very likely to lead the observer astray.

Another caution must also be given, viz.: that the knowledge thus obtained will only apply to a limited area; this is a natural result of the distribution of life in "provinces," during past as well as present time; consequently in comparing districts which are wide apart we cannot be sure of the absolute contemporaneity of deposits which may contain similar fossils, we can only say that the relative order of succession is the same in both regions. Mr. Jukes says, "It is yet doubtful whether these specific differences, existing together with generic identities, be due to a want of exact synchronism in the age of the beds or to the geographical distribution and limitation of the life of the period, whether in fact they are the result of time or space." Where, however, the areas are widely separated, the former is the more probable cause, and in correlating the

* "Manual of Geology," Jukes and Geikie, p. 512.

series of beds in each, we should be careful to speak of them only as *homotaxial* and not *contemporaneous*.

For instance, rocks in Bohemia and Scandinavia, containing the same genera of trelobites as are found in our lingula flags, have been correlated with them and with one another, as if they were absolutely contemporaneous; owing, however, to the above considerations this cannot be regarded as accurately true, though it is certain that they occupy the same place in the geological series of the several countries.

From the preceding considerations we learn that palæontological science, although so useful a handmaiden to that of geology, is not always to be implicitly trusted in her guidings and indications. Geognosy, though a more reticent, is perhaps a safer guide, when her counsel is obtainable; but we should constantly avail ourselves of the assistance offered by both on our geological ways, and never lose sight of either except where the exigencies of the road oblige us.

CHAPTER IV.

Characteristic Fossils—Table of Fossils.

Characteristic Fossils.—The interruptions of continuity in the conditions under which the rocks were formed, and the resulting variations in their enclosed life-remains, afford a means for their classification. They are thus divided into great groups or systems, representing life-periods and eras, corresponding to such divisions and sub-divisions.

"Each of the great groups has an assemblage of fossils peculiar to it, so that the general assemblage of fossils found in one group is not found in any other group, either above or below. As minor exceptions to this rule, particular species of fossils seem occasionally to range in to two, or perhaps even three, adjacent groups, occurring perhaps in the upper part of one group, ranging through the whole of the group above it, and appearing in the lower part of the group above that. Some species, on the other hand, are found only in a very small part of one group, either throughout the lateral extension of the beds wherever they occur, or sometimes limited to some small locality in those beds.

"When a single species or an assemblage of several species occurs in a group of rocks, whether large or small, and has never been found except in that group of rocks, and is almost always found wherever the group extends, we may speak of these as the *characteristic species* of the group. It occasionally happens that the fossils of such a group are so nearly allied biologically that naturalists form them into a genus, or into one or two genera, which may then be spoken of as equally characteristic."*

A list of the more common characteristic fossils has been compiled from various sources,† and is given below, arranged not in the order of succession of the rock formations, but alphabetically, so that if a fossil be known the approximate (if not exact) geological position of the rock from which it has been derived can readily be determined.

* "Manual of Geology," Jukes and Geikie, p. 502.

† Murchison's *Siluria.*
Lyell's *Manual, Students' Elements,* &c.
Jukes and Geikie's *Manual.*
Buckland's *Bridgewater Treatise.*
Mantell's *Medals, Wonders of Geology,* &c.
Phillips' *Manual, Palæozoic Fossils,* &c.
M'Coy, *Palæozoic Fossils.*
Portlock, *Geological Reports.*
Owen, *Palæontology.*
Wright, *Brit. Foss. Echinodermata.*
King, *Permian Fossils.*
Geological Magazine.
Tabular View of British Fossils stratigraphically arranged.
Publications of *H.M. Geological Survey.*
" " the *Geological Society.*
" " *Palæontographical Society.*
&c., &c., &c.

LIST OF CHARACTERISTIC FOSSILS.

ACTINOZOA.

GENUS.	SPECIES.	
Acervularia	luxurians	U. Silurian. *Wenlock.*
Alveolites	Labechei	U. Silurian. *Wenlock.*
	repens	” ”
	suborbicularis (*characteristic*)	L. Devonian.
Amplexus	coralloides	Carboniferous.
Anabacia	hemispherica	L. Oolite. *Inf. Oo.*
Arachnophyllum	Hennakii	Devonian.
Balanophyllia	calyculus	O. Pliocene. *R. Crag.*
Calamophyllia	radiata	L. Oolite. *Gt. Oo.*
Eunomia	Stokesii	M. Oolite. *Cor. Oo.*
Caryophillia	annularis	M. Oolite. *Cor. Oo.*
Thecosmilia		
Clisiophyllum	sp.	Carboniferous.
Cœlosmilia	laxa	U. Cretaceous. *U. Chalk.*
Cyathaxonia	Siluriensis	U. Silurian. *Ludlow.*
Cyathina	Bowerbankii	U. Cretaceous. *Gault.*
Cyathophyllum	angustum	Silurian. *Llandovery.*
	cœspitosum, *peculiar to Devonian*	M. and U. Devonian.
	sp.	Carboniferous.
Cyclocyathus	Fittoni	U. Cretaceous. *Gault.*
Cystiphyllum	vesiculosum	Devonian.
Dasmia	Sowerbyi	L. Eocene.
Favosites	cervicornis	L. and M. Devonian.
	fibrosus	Silurian. *Llandovery to Ludlow.*
	Gotlandicus	Silurian. *Bala* (*Caradoc*) *to Ludlow.*
Flabellum	Woodii	O. Pliocene. *Wh. Crag.*
Halysites	catenularius	U. and L. Silurian. *Llandeilo to Ludlow.*
Heliolites	Grayi	U. Silurian. *Wenlock.*
	pyriformis, *peculiar to*	Devonian.
Holocystis	elegans	L. Cretaceous. *U. Neocomian.*

Isastrea -	- Conybeari	- L. Oolite. *Gt. Oo.*
	explanata	- M. Oolite. *Cor. Oo.*
	Murchisoni	- Lias.
	oblonga -	- U. Oolite. *Portland.*
Litharea -	- Websteri	- M. Eocene.
Lithostrotion	- affine -	- Carboniferous.
	basaltiforme	- ,,
Lonsdaleia -	- floriformis	- Carboniferous.
Michelinia -	- favosa	- Carboniferous.
Micrabacia -	- coronula	- U. Cretaceous. *U. Gr.*
Monticulipora	- favulosa	- L. Silurian. *Llandeilo.*
Montivaltia	- cuneata	- M. Lias. *Marlstone.*
	trochoides	- L. Oolite. *Inf. Oo.*
Omphyma -	- turbinatum	- Silurian. *Bala to Wenlock.*
Paracyathus	- caryophillus	- L. Eocene.
Parastrœa	- striata -	- U. Cretaceous. *U. Gr.*
Petraia -	- bina -	- Silurian. *U. Llandovery and Wenlock.*
	Celtica -	- L. M. and U. Devonian.
	elongata	- Silurian. *U. Llandovery.*
Pleurodictyum	- problematicum	L. and M. Devonian.
Polycelia -	- profunda (*characteristic*) -	M. Permian. *Mag. L.*
Protoseris -	- sp.	- M. Oolite. *Cor. Oo.*
Solenastrœa	- cellulosa	- U. Eocene.
Stenopora -	- fibrosa -	- Silurian. *Llandeilo to Ludlow.*
Stephanophyllia	- Bowerbankii	- U. Cretaceous. *L. Ch.*
Stromatopora	- placenta	- Devonian.
Stylina -	- tubulifera	- M. Oolite. *Cor. Oo.*
Syringopora	- bifurcata	- Silurian. *Llandovery to Ludlow.*
	ramulosa	- Carboniferous.
Thamnastrœa	- arachnoides	- M. Oolite. *Cor. Oo.*
	concinna	- L. and M. ,, *Gt. and Cor. Oo.*
Theococyathus	- Moorei	- L. Lias.
Trochocyathus	- conulus	- U. Cretaceous. *Gault.*
Trochosmilia	- sulcata	- U. Cretaceous. *Gault.*
Turbinolia	- Bowerbankii	- M. Eocene.
Zaphrentis -	- sp.	- Carboniferous.

ANNELIDA.

Arenicolites	- didyma	- Cambrian.
	linearis	- L. Silurian. *Stiper Stones.*
Chondrites	- acutangulus	- L. Silurian. *Llandeilo.*
	informis	- ,, ,,

Cornulites	serpularius	Silurian. *Llandovery to Ludlow.*
Crossopodia	lata	U. Silurian. *Ludlow.*
	Scotica	L. Silurian. *Bala.*
Histioderma	Hibernica	L. Cambrian. *Longmynd.*
Nerites	Cambrensis	L. Silurian. *Llandeilo.*
	Sedgwickii	,, *Llandeilo & Bala.*
Palæochorda	major	L. Silurian. *Llandeilo.*
	minor	,, ,,
Serpula	amphisbœna	U. Cretaceous. *L. Chalk.*
	articulata	,, *Gault.*
	coacervites	U. Oolite. *Purbeck.*
	tetragona	L. Oolite. *For. Marb.*
	vertebralis	M. Oolite. *Oxf. Clay.*
Serpulites	dispar	U. Silurian. *Ludlow.*
	longissimus	,, *Wenlock and Ludlow.*
Spirorbis	carbonarius	Carboniferous.
Tentaculites	annulatus	M. Devonian.
	ornatus	Silurian. *Bala to Wenlock.*
	tenuis	U. Silurian. *Ludlow.*
Trachyderma	coriaceum	,, ,,
	læve	L. Silurian. *Bala.*
	squamosum	U. Silurian. *Ludlow.*
Vermicularia	Bognoriensis	L. Eocene.
	concava	U. Cretaceous. *U. Gr.*

AVES.

Halcyornis	toliapicus	L. Eocene.
Lithornis	vulturensis	L. Eocene.
Palæornis	Cliftii	L. Cretaceous. *Wealden.*

BRACHIOPODA.

Athyris	planosulcata	Carboniferous.
Atrypa	desquamata	L. M. and U. Devonian.
	hemispherica	Silurian. *Llandovery.*
	marginalis	,, ,,
	reticularis	,, *Llandovery to Devonian.*
Calceola	sandalina, *peculiar to*	M. Devonian.
Camarophoria	crumena=Schlotheimi (*characteristic*)	M. Permian. *Mag. L.*

Chonetes	Hardrensis	L. M. and U. Devonian.
	lata	U. Silurian. *Downton.*
Crania	Ignabergensis	U. Cretaceous. *U. Chalk.*
	Parisiensis	,, ,,
Discina (Orbicula)	nitida	Carboniferous and M. Permian.
	punctata	U. Silurian. *Bala.*
	rugata	Silurian. *Wenlock and Ludlow.*
	striata	Silurian. *Ludlow.*
Leptæna (*Silurian to Lias*)	Moorei	U. Lias.
	sp.	Silurian. *U. Llandovery.*
Lingula	attenuata	L. Silurian. *Llandeilo.*
	cornea	U. Silurian. *Ludlow and Downton.*
	Crednerii	Carboniferous and M. Permian.
	crumena	U. Silurian. *U. Llandovery.*
	Dumortieri	O. Pliocene. *Wh. Crag.*
	lata	U. Silurian. *Ludlow.*
	Lewisii	,, ,,
	mytiloides (*characteristic*)	M. Permian. *Marl-Slate.*
	ovalis	M. and U. Oolite.
	parallela	U. Silurian. *U. Llandovery.*
	striata	,, *Ludlow.*
	tenuis[1]	L. Eocene.
Lingullela	Davisii	U. Cambrian. *Lingula flags.*
	lepis	,, ,, ,,
Magas	pumila	U. Cretaceous. *U. Chalk.*
Meristella	plebeia	M. Devonian.
Obolus	transversus	U. Silurian. *Wenlock.*
Orbiculoidea	Forbesii	U. Silurian. *Wenlock.*
Orthis	Actoniæ	L. Silurian. *Bala and Llandovery.*
	alata	L. Silurian. *Llandeilo.*
	arcuata (*characteristic*)	L. Devonian.
	caligramma	Silurian. *L. Llandovery.*
	elegantula	,, *Llandeilo to Ludlow.*
	flabellum	L. Silurian. *Llandeilo.*
	granulosa	L. and M. Devonian.
	insularis	L. Silurian. *Llandeilo.*
	lata	Silurian. *U. Llandovery.*

Orthis -	- lenticularis	- U. Cambrian. *Lingula flags.*
	lunata -	- U. Silurian. *Ludlow.*
	orbicularis	- „ „
	resupinata	- Carboniferous.
	reversa	- Silurian. *U. Llandovery.*
	rustica	- U. Silurian. *Wenlock.*
	vespertilio	- L. Silurian. *Llandeilo.*
Pentamerus	- galeatus	- U. Silurian. *Wenlock and Ludlow.*
	globosus	- Silurian. *U. Llandovery.*
	Knightii	- „ *Wenlock and Ludlow.*
	lens -	- Silurian. *U. Llandovery.*
	levis (*characteristic*)	- „ *L. Llandovery.*
	lirata -	- „ *U. Llandovery.*
	oblongus (*characteristic*)	- Silurian. *U. Llandovery.*
	undatus -	- Silurian.
Productus -	- aculeatus	- Carboniferous.
	giganteus	- „
	hemisphæricus	„
	horridus (*characteristic*)	- M. Permian. *Mag. L.*
	prælongus	- U. Devonian.
	scabriculus	- Carboniferous.
	semireticulatus	„
	sp. -	- M. Permian. *Marl-slate.*
Retzia -	- Baylei -	- U. Silurian. *Wenlock.*
Rhynconella	- acuminata	- Carboniferous.
	augustifrons	- Silurian. *U. Llandovery.*
	concinna	- L. Oolite. *Gt. Oo.*
	crassa -	- Silurian. *L. Llandovery.*
	Cuvieri -	- U. Cretaceous. *L. Chalk.*
	Gibbsii -	- L. Cretaceous. *L. Gr.*
	inconstans	- U. Oolite. *Kim. Clay.*
	latissima -	- U. Cretaceous. *U. Gr.*
	navicula -	- U. Silurian. *Wenlock and Ludlow.*
	neglecta	- Silurian. *U. Llandovery.*
	nucula	- „ *Llandovery to Ludlow.*
	obsoleta	- L. to U. Oolite.
	octoplicata	- U. Cretaceous. *U. Chalk.*
	pleurodon	- Carboniferous.
	psittacea	- Newer Pliocene.

Rhynconella	rimosa	L. and M. Lias.
	spinosa	L. Oolite. *Inf. Oo.*
	tetahedra	M. Lias.
	varians	L. and M. Oolite. *Gt. and Cor. Oo.*
	Wilsoni	Silurian. *Llandovery to Ludlow.*
Siphonotreta	Anglica	U. Silurian. *Wenlock.*
	micula	L. Silurian. *Llandeilo flags.*
Spirifera (*Silurian to Lias*)	alata	M. Permian. *Mag. L.*
	cuspidata	Carboniferous.
	disjuncta = Verneuillii	U. Devonian.
	glabra	Carboniferous.
	lineata	M. and U. Devonian.
	lævicosta	L. and M. Devonian.
	pinguis	Carboniferous.
	plicatella	Silurian. *Llandovery to Ludlow.*
	rotundata	Carboniferous.
	speciosa	L. and M. Devonian.
	striata	Carboniferous.
	trigonalis	,,
	undulata	Permian.
	Walcottii	L. and M. Lias.
Spiriferina	cristata (*characteristic*)	M. Permian. *Mag. L.*
Stringocephalus	Burtini *exclusively*	M. Devonian.
Strophalosia	caperata	U. Devonian.
	Goldfussii (*characteristic*)	M. Permian. *Mag. L.*
Strophomena	complanata	L. Silurian. *Bala.*
	compressa	Silurian. *U. Llandovery.*
	depressa	,, *Bala to Ludlow.*
	englypha	,, *Llandovery to Ludlow.*
	grandis	L. Silurian. *Bala.*
	imbrex	U. Silurian. *Wenlock.*
	rhomboidalis	Silurian and Devonian.
Terebratella	pectita	U. Cretaceous. *U. Gr.*
Terebratula	biplicata	,, ,,
	bisinuata	M. Eocene.
	carinata	L. Oolite. *Inf. Oo.*
	carnea	U. Cretaceous. *U. Chalk.*

Terebratula	coarctata	L. Oolite. *Gt. Oo.*
	digona	Oolite ”
	fimbria	” *Inf. Oo.*
	grandis	Older Pliocene. *Wh. and R. Crag.*
	hastata	Carboniferous.
	impressa	L. and M. Oolite. *Gt. and Cor. Oo.*
	intermedia	L. Oolite. *For. Marb.*
	maxillata	” *Gt. Oo.*
	numismalis	L. and M. Lias.
	obovata	L. Oolite. *For. Marb.*
	ornithocephala	L. and M. Oolite. *Inf. Gt. and Cor. Oo.*
	perovalis	L. Oolite. *Inf. Oo.*
	sella	L. Cretaceous. *L. Gr.*
Terebratulina	striata=caput serpentis	U. Cretaceous. *U. Chalk, and still living.*
	striatula	L. Eocene.
Terebrirostra	lyra	U. Cretaceous. *U. Gr.*
Thecidium	triangulare	U. Lias and L. Oolite *to For. Marb.*
Uncites	gryphus *exclusively*	M. Devonian.

CEPHALOPODA.

Actinoceras	giganteum	Carboniferous.
Ammonites	angulatus	L. Lias.
	auritus	U. Cretaceous. *U. Gr.*
	bifrons	U. Lias.
	biplex	U. Oolite. *Kim. Clay.*
	Braikenridgii	L. Oolite. *Inf. Oo.*
	Brocchii	” ”
	Brodici	” ”
	Brongniartii	” ”
	Bucklandi	L. Lias.
	Calloviensis	M. Oolite. *Oxf. Clay.*
	capricornis	M. Lias.
	communis	U. Lias.
	complanatus	U. Cretaceous. *L. Ch. and Marl.*
	cordatus	M. Oolite. *Oxf. Clay.*
	dentatus	U. Cretaceous. *Gault.*
	Deshayesii	L. Cretaceous. *Punfield and Speeton.*

Ammonites -	- discus -	- L. Oolite. *For. Marb.*
	excavatus	- M. Oolite. *Oxf. Clay.*
	giganteus	- U. Oolite. *Portland.*
	gracilis -	- L. Oolite. *Gt. Oo.*
	heterophillus	- U. Lias.
	Humphresianus	L. Oolite. *Inf. Oo.*
	interruptus	- U. Cretaceous. *Gault.*
	Jason -	- M. Oolite. *Oxf. Clay.*
	Lamberti	- " "
	lautus -	- U. Cretaceous. *Gault.*
	macrocephalus	- L. and M. Oolite. *Gt. Oo. and Oxf. Clay.*
	margaritatus	- M. Lias.
	Martini -	- L. Cretaceous. *L. Gr.*
	modiolaris = subloevis -	} M. Oolite. *Oxf. Clay.*
	Murchisonæ	- L. Oolite. *Inf. Oo.*
	Noricus -	- L. Cretaceous. *Speeton Clay.*
	obtusis -	- L. Lias.
	Parkinsoni	- L. Oolite. *Inf. Oo.*
	perarmatus	- M. Oolite. *Cor. Oo.*
	planorbis	- L. Lias.
	Rhotomagensis (*characteristic*)	} U. Cretaceous. *Ch. Marl.*
	rostratus	- " *U. Gr.*
	rotundus	- U. Oolite. *Kim. Clay.*
	serpentinus	- U. Lias.
	spinatus	- M. Lias.
	splendens	- U. Cretaceous. *Gault.*
	triplicatus	- M. Oolite. *Kim. Clay.*
	varians -	- U. Cretaceous. *L. Ch. & Marl.*
	varicosus	- U. Cretaceous. *Gault.*
	vertebralis	- M. Oolite. *Cor. Oo.*
Ancyloceras = Crioceras = Scaphites	- Calloviense	- M. Oolite. *Oxf. Clay.*
	Duvallei	- L. Cretaceous. *L. M. and U. Neo.*
	equalis -	- U. Cretaceous. *L. Chalk and Marl.*
	gigas -	- L. Cretaceous. *L. Gr.*
	spinigerum	- U. Cretaceous. *Gault.*
Ascoceras -	- Barrandii	- U. Silurian. *Ludlow.*
Baculites (*never in rocks newer than Cretaceous*)	- anceps -	- U. Cretaceous. *L. Chalk.*

Belemnitella	mucronata	U. Cretaceous.	*U. Chalk.*
	plena	"	*L. Chalk.*
Belemnites	abbreviatus	M. Oolite.	*Cor. O.*
	dilatatus	L. Cretaceous.	*L. Gr.*
	ellipticus	L. Oolite.	*Inf. Oo.*
	elongatus	M. Lias.	
	fusiformis	L. Oolite.	*Gt. Oo.*
	hastatus	M. Oolite.	*Oxf. Clay.*
	minimus	U. Cretaceous.	*Gault.*
	Puzosianus	M. Oolite.	*Oxf. Clay.*
	tubularis	U. Lias.	
	Waterhousei	L. Oolite.	*Gt. Oo.*
Beloptera	belemnitoidea	M. Eocene.	
Belosepia	sepioidea	L. Eocene.	
Clymenia	linearis	U. Devonian.	
	lævigata	M. and U. Devonian.	
	striata	U. Devonian.	
	undulata	"	
Cyrtoceras	approximatum	Silurian.	*U. Llandovery.*
	Gesneri	Carboniferous.	
	tredecimale	M. Devonian.	
	Vernuillianum	Carboniferous.	
	sp.	L. Silurian.	*Llandeilo flags.*
Geoteuthis	Boltensis	Lias.	
Goniatites	crenistria	Carboniferous.	
	Listeri	"	
	sphæricus	"	
	subsulcatus	U. Devonian.	
Gyroceras	sp.	M. Devonian.	
Hamites (*never in rocks newer than Cretaceous*)	attenuatus	U. Cretaceous.	*Gault.*
	rotundus	"	"
	simplex	"	*L. Chalk.*
	spiniger=Ancyloceras spinigerum	"	*Gault.*
Lituites=Trochoceras	articulatus	U. Silurian.	*Ludlow.*
	giganteus	"	*Wenlock and Ludlow.*
	Hibernicus	L. Silurian.	*Bala.*
	undosus	Silurian.	*U. Llandovery.*
Nautilus	Baberi	L. Oolite.	*Gt. Oo.*
	biangulatus=carinatus	Carboniferous.	

Nautilus -	- Bowerbankianus (*characteristic*) -	M. Permian. *Mag. L.*
	centralis -	L. Eocene.
	elegans - -	U. Cretaceous. *L. Chalk.*
	Frieslebeni (*characteristic*)	M. Permian. *Mag. L.*
	hexagonus -	M. Oolite. *Oxf. Clay.*
	imperialis -	L. Eocene.
	plicatus -	L. Cretaceous. *U. Neo.*
	sinuatus -	L. Oolite. *Inf. Oo.*
	truncatus -	L. Lias.
	zic-zac -	L. Eocene.
Orthoceras -	- annulatum -	Silurian. *Bala to Wenlock.*
	Avelinii -	L. Silurian. *Llandeilo flags.*
	Barrandii -	„ *U. Llandovery.*
	bullatum -	U. Silurian. *Llandovery to Ludlow.*
	duplex -	L. Silurian. *Llandeilo flags.*
	laterale -	Carboniferous.
	Ludense -	U. Silurian. *Ludlow.*
	Maclareni -	„ *Wenlock.*
	Steinhaueri -	Carboniferous.
	tenuicinctum -	L. Silurian.
	vagans -	„ *Bala.*
	sp. - -	Cambrian. *Tremadoc.*
	sp. - -	M. Devonian.
Phragmoceras	- ventricosus, and 5 other species -	U. Silurian. *Wenlock and Ludlow.*
Poterioceras	- approximatum	L. Silurian. *Bala.*
	fusiforme -	Carboniferous.
Tretoceras -	- bisiphonatum -	Silurian. *U. Llandovery.*
Trigonellites	- latus - -	U. Oolite. *Kim. Clay.*
Turrilites -	- costatus - -	U. Cretaceous. *L. Chalk.*

Crustacea.

Acidaspis -	- Barrandii -	U. Silurian. *Wenlock.*
	callipareos -	Silurian. *U. Llandovery.*
	coronata -	U. Silurian. *Ludlow.*
	Jamesii -	L. Silurian. *Bala.*
Æglina -	- binodosa (*characteristic*) -	L. Silurian. *Stiper-Stones.*
	mirabilis -	„ *Bala.*

Agnostus -	princeps -	Cambrian. *Lingula flags.*
	trinodus	L. Silurian. *Bala.*
Ampyx -	nudus -	L. Silurian. *Llandeilo flags.*
	parvulus	U. Silurian. *Wenlock and Ludlow.*
Angelina -	sp. -	U. Cambrian. *Tremadoc.*
Anoplenus -	sp. -	L. Cambrian. *Menevian.*
Archæoniscus	Edwardsii	U. Oolite. *Purbeck.*
Asaphus -	laticostatus	L. Silurian. *Llandeilo flags.*
	Powisii	" *Llandeilo and Bala.*
	tyrannus	L. Silurian. *Llandeilo.*
Astacoderma	9 species	U. Silurian. *Downton.*
Balanus -	balanoides	Post-Pliocene.
	crenatus	"
	porchatus	"
Belinurus -	Regina -	Carboniferous.
	rotundatus	"
	trilobitoides	"
Beyrichia -	complicata	L. Silurian. *Llandeilo and Bala.*
	Klœdeni	Silurian. *Bala to Downton.*
	siliqua -	U. Silurian. *Ludlow.*
Brachymetopus=Phillipsia	Ouralicus	Carboniferous.
	pustulata	"
Bronteus -	flabellifer (*characteristic*)	M. Devonian.
Calymene -	Blumenbachii	Silurian. *Bala to Ludlow.*
	brevicapitata	L. Silurian. *Llandeilo and Bala.*
	parvifrons	L. Silurian. *Llandeilo.*
Ceratiocaris	Murchisonii, and 10 other species	U. Silurian. *Ludlow.*
Cheirurus -	clavifrons	L. Silurian. *Bala.*
Conocoryphe	depressa	Cambrian. *Lingula flags.*
	invita -	" "
Cyphaspis -	pygmæus	U. Silurian. *Wenlock.*
Cypridea=Cypris	fasiculata	U. Oolite. *M. Purbeck.*
	gibbosa	" *U. Purbeck.*
	granulata	" *M. Purbeck.*
	leguminella	" *U. Purbeck.*
	punctata	" *L. Purbeck.*
	Purbeckensis	" "
	spinigera	L. Cretaceous. *Wealden.*

Cypridea	striata-punctata	U. Oolite.	*M. Purbeck.*
	tuberculata	,,	*U. Purbeck.*
	Valdensis	L. Cretaceous.	*Wealden.*
	sp.	U. Eocene.	
	sp.	L. Miocene.	
Cypridina	serrato-striata	U. Devonian.	
Cythere	inflata	Carboniferous.	
Dikelocephalus	sp.	U. Cambrian.	*Tremadore.*
Dithyocaris	Colei	Carboniferous.	
Encrinurus	punctatus	Silurian.	*Llandovery to Ludlow.*
	variolaris	U. Silurian.	*Wenlock.*
Errinnys	venulosa	L. Cambrian.	*Menevian.*
Eryon	antiquus	Lias.	
	Barrovensis	,,	
Estheria	elliptica	L. Cretaceous.	*Wealden.*
	minuta (*characteristic*)	Trias.	? *Keuper and Penarth.*
	sp.	M. Old Red.	
	sp.	L. Oolite.	*Inf. Oo.*
Eurypterus	abbreviatus, and 6 other species	U. Silurian.	*Ludlow.*
	linearis	,,	*Ludlow & Downton.*
	megalops, *peculiar to*	U. Silurian.	*Downton.*
	pygmæus	,,	*Ludlow and Downton.*
	sp.	L. Old Red.	
Glyphœa	Liassica	Lias.	
	rostrata	L. and M. Oolite.	*Gt. Oo. and Cor. Oo.*
	scabrosa	M. Oolite.	*Cor. Oo.*
Griffithides	globiceps	Carboniferous.	
Harpes	Flanagani	L. Silurian.	*Bala.*
Homalonotus	arcuatus (*characteristic*)	L. Devonian.	
	bisulcatus	Silurian.	*Bala and Llandovery.*
	delphinocephalus	U. Silurian.	*Wenlock.*
	Herschellii	L. Devonian.	
	Knightii	U. Silurian.	*Ludlow.*
	Ludensis	,,	,,
Hoploparia	Bellii	L. Eocene.	

Hymenocaris -	vermicauda (*characteristic*)	U. Cambrian. *Lingula flags.*
Illænus -	Barriensis -	Silurian. *Llandovery and Wenlock.*
	Bowmanni -	Silurian. *Llandeilo, Bala, and Llandovery.*
	Davisii - -	L. Silurian. *Bala.*
	perovalis -	„ *Llandeilo.*
Leperdita -	sp. - -	U. Silurian. *Ludlow and Downton.*
Lichas -	Anglicus -	U. Silurian. *Wenlock and Ludlow.*
	Hibernicus -	L. Silurian. *Bala.*
	laxatus - -	Silurian. *Bala and Llandovery.*
Megacheirus -	Pearcei - -	M. Oolite. *Oxf. Clay.*
Meyeria -	Vectensis -	L. Cretaceous. *L. Gr.*
Microdiscus -	sp. - -	L. Cambrian. *Menevian.*
Notopocorystes -	Beachei -	U. Cretaceous. *Gault.*
	Stokesii - -	„ „
Ogygia -	Buchii - -	L. Silurian. *Llandeilo.*
	Selwynii (*characteristic*) -	L. Silurian. *Stiper-Stones.*
Olenus -	alatus - -	U. Cambrian. *Lingula flags.*
	micrurus -	„ „
Paradoxides -	Davidis, *peculiar to* -	L. Cambrian. *Menevian.*
	Hicksii - -	U. Cambrian. *Lingula flags.*
Phacops -	apiculatus -	L. Silurian. *Llandeilo and Bala.*
	caudatus -	Silurian. *Llandovery to Ludlow.*
	Downingiæ -	U. Silurian. *Wenlock and Ludlow.*
	longicaudatus -	U. Silurian. *Wenlock and Ludlow.*
	Stokesii - -	Silurian. *L. and U. Llandovery.*
Plutonia -	Sedgwickii -	L. Cambrian. *Longmynd.*
Pollicipes -	concinnus -	M. Oolite. *Oxf. Clay.*
Prœtus -	latifrons -	Silurian. *Llandovery to Ludlow.*
Pterygotus -	eggs of=Parka decipiens -	U. Silurian and L. Old Red.
	Anglicus -	L. Old Red.

Pterygotus	Banksii	U. Silurian.	*Downton.*
	bilobus	"	*Ludlow.*
	Ludensis, *peculiar to*	"	*Downton.*
	problematicus and several other species	"	*Ludlow.*
Remopleurides	dorso-spinifer	L. Silurian.	*Bala.*
	granulatus	M. and U. Devonian.	
	latifrons (*characteristic of Devonian*)	"	"
	laciniatus	L. M. and U. Devonian.	
Sphœrexochus	mirus	Silurian.	*Bala and Wenlock.*
Staurocephalus	globiceps	L. Silurian.	*Bala.*
	Murchisonii	Silurian.	*Bala to Wenlock.*
Trinucleus	Caractaci	L. Silurian.	*Bala.*
	fimbriatus	"	*Llandeilo.*
	Lloydii	"	"
	seticornis	"	*Bala.*
Zanthopsis	tuberculata	L. Eocene.	

Echinodermata.

Acrosalenia	decorata	M. Oolite.	*Cor. Oo.*
	hemicidaroides	L. Oolite.	*For Marb.*
	minuta	L. Lias.	
Actinocrinus	pulcher	U. Silurian.	*Wenlock.*
	triacontadactylus	Carboniferous.	
Agelacrinus	Buchianus	L. Silurian.	*Bala.*
Ananchytes (*genus exclusively Cretaceous*)	ovatus	U. Cretaceous.	*L. and U. Chalk.*
	subglobosus	U. Cretaceous.	*L. and U. Chalk.*
Apiocrinus	Parkinsoni=rotundus	L. Oolite.	*For. Marb.*
Archæocidaris	Urii	Carboniferous.	
Astropecten	crispatus	L. Eocene.	
Cardiaster	granulosus	U. Cretaceous.	*U. Chalk.*
	Benstedi	L. Cretaceous.	*L. Gr.*
Catopygus	carinatus	U. Cretaceous.	*U. Gr.*
Cidaris	coronata	M. Oolite.	*Cor. Oo.*
	Edwardsii	M. Lias.	

Cidaris	florigemma	M. Oolite.	*Cor. Oo.*
	peronata	U. Cretaceous.	*U. Chalk.*
Codonaster	*genus peculiar to*	Carboniferous.	
Collyrites	ringens	L. Oolite.	*Inf. Oo.*
Comatula	Brownii	O. Pliocene.	*Wh. Crag.*
Crotalocrinus	rugosus	U. Silurian.	*Wenlock.*
Cupressocrinites	sp.	Devonian.	
Cyathocrinus	calcaratus	Carboniferous.	
	caryocrinoides	”	
	goniodactylus	U. Silurian.	*Wenlock.*
	planus	Carboniferous.	
Diadema	Bennettiæ	U. Cretaceous.	*U. Gr.*
Discoidea	cylindrica	”	*L. Chalk.*
	subuculus	”	*U. Gr.*
Echinocyamus	pusillus	O. Pliocene.	*Wh. Crag.*
Echino-encrinites	armatus	U. Silurian.	*Wenlock.*
Echino-sphœrites	aurantium	L. Silurian.	*Bala.*
	Balticus (*characteristic*)	”	”
Echinus	Dröbachiensis	Post-Pliocene.	
	granulosus	U. Cretaceous.	*U. Gr.*
	perlatus	L. and M. Oolite.	*Inf. Gt. and Cor. Oo.*
	Woodwardii	O. Pliocene.	*Wh. Crag.*
Encrinites	sp.	L. Devonian and Trias.	
Eucalyptocrinus	decorus	U. Silurian.	*Wenlock.*
Eupatagus	Hastingsiæ	M. Eocene.	
Extracrinus= (Pentacrinus)	Briareus	L. Lias.	
Galerites	albo-galerus	U. Cretaceous.	*U. Chalk.*
Goniaster	Parkinsoni	”	”
	Stokesii	L. Eocene.	
Haploaster	gracilis	Post-Pliocene.	
Hemiaster	Bailyi	U. Cretaceous.	*Gault.*
Hemicidaris (*genus Oolitic*)	Davidsoni	U. Oolite.	*Portland.*
	intermedia	L. and M. Oolite.	*Gt. and Cor. Oo.*
	minor	L. Oolite.	*Gt. Oo.*
	Purbeckensis	U. Oolite.	*Purbeck.*
Hemicosmites	sp.	L. Silurian.	*Bala.*
Hemipneustes	Fittoni	L. Cretaceous.	*L. Gr.*
Marsupiocrinus	cœlatus	U. Silurian.	*Wenlock.*
Marsupites	Milleri	U. Cretaceous.	*Chalk.*
	ornatus	”	*U. Chalk.*

Micraster	cor-anguinum	U. Cretaceous. *U. Chalk.*
Nucleolites	Agassizii	L. Oolite. *Inf. Oo.*
	clunicularis	" *Cornbrash.*
	dimidiatus = sculatus	L. and M. Oolite. *Gt. and Cor. Oo.*
	orbicularis	L. and M. Oolite. *Gt. and Cor. Oo.*
	sinuatus	L. and M. Oolite. *Gt. and Cor. Oo.*
Ophioderma	Egertoni	M. Lias.
	tenuibranchiata	"
Ophiura	Wetherellii	L. Eocene.
Palæaster	asperrimus	L. Silurian. *Bala.*
	coronella	Silurian. *U. Llandovery.*
	obtusus	L. Silurian. *Bala.*
	Ruthveni	U. Silurian. *Ludlow.*
Palæchinus	gigas	Carboniferous.
	sphæricus	"
Palæocoma	Colvini, and 3 other species	U. Silurian. *Ludlow.*
Pentacrinus (*Lias to London clay*)	Fittoni	U. Cretaceous. *Gault.*
	sub-basaltiformis	L. Eocene.
	several species	Lias.
Pentremites	*genus peculiar to*	Carboniferous.
	Derbiensis, &c., &c.	"
Periechocrinus	moniliformis	Silurian. *Llandovery and Wenlock.*
Platycrinus	*genus characteristic of*	Carboniferous.
	lævis, &c. &c.	"
Pleurocystites	Rugeri	Silurian. *U. Llandovery.*
Poteriocrinus	*genus characteristic of*	Carboniferous.
	granulosus, &c., &c.	"
Protaster	Miltoni, and 3 other species	U. Silurian. *Ludlow.*
	sp.	L. Silurian. *Bala.*
Pseudocrinites	bifasciatus	U. Silurian. *Wenlock.*
	quadrifasciatus	" "

Pseudodiadema -	pentagonum -	L. Oolite. *Gt. Oo.*
Pygaster -	- semisulcatus -	L. and M. Oolite. *Gt. and Cor. Oo.*
Pygurus -	- pentagonalis -	L. and M. Oolite. *Gt. and Cor. Oo.*
Rhodocrinus	- bursa -	- Carboniferous.
Salenia -	- Austeni -	- U. Cretaceous. *L. Chalk.*
	personata -	,, *U. Gr.*
	punctata -	L. Cretaceous. *L. Gr.*
Spatangus -	- radiatus -	- U. Cretaceous. *U. Chalk.*
Sphæronites = Cystidæ -	- Litchi -	- L. Silurian. *Bala.*
Taxocrinus -	- tesseraconta-dactylus -	U. Silurian. *Wenlock.*
	Orbignyi -	,, *Ludlow.*
Temnechinus	- excavatus -	O. Pliocene. *Wh. and R. Crag.*
Uraster -	- Gaveyi -	- M. Lias.

Gasteropoda.

Achatina -	- costellata -	U. Eocene.
Acroculia -	- euomphaloides	U. Silurian. *Ludlow.*
	haliotis -	- Silurian. *Llandovery and Wenlock.*
	sp. -	- M. Devonian.
	sp. -	- Carboniferous.
Actæon -	- affinis -	- U. Cretaceous. *U. Gr.*
Alaria -	- atractoides	- L. Oolite. *Gt. Oo.*
	composita	- M. Oolite. *Oxf. Clay.*
	trifida -	- L. and M. Oolite. *Gt. and Cor. Oo.*
Ancillaria -	- buccinoides	- M. Eocene.
Aporrhais -	- Sowerbyi	- L. Eocene.
Avellana -	- cassis -	- U. Cretaceous. *L. Chalk.*
Buccinum -	- Grænlandicum	Post-Pliocene.
	sp. -	- L. Oolite. *Gt. Oo.*
Bulimus -	- ellipticus	- U. Eocene.
Bulla - -	- elongata	- L. and M. Oolite. *Gt. and Cor. Oo.*
Bullæa -	- sculpta -	- O. Pliocene. *Wh. Crag.*
Cancellaria -	- evulsa -	- M. Eocene.
	muricata	- U. Eocene.
	sp. -	- L. Eocene.
Cassidaria -	- bicatenata	- O. Pliocene. *Wh. Crag.*
	Smithii -	- L. Eocene.

Cerithium -	- carbonarium -	L. Cretaceous. *Wealden.*
	elegans -	- U. Eocene and L. Miocene.
	funatum	- L. Eocene.
	giganteum	- M. Eocene.
	muricatum	- M. Oolite. *Cor. Oo.*
	mutabile	- U. Eocene.
	plicatum	- U. Eocene and L. Miocene.
	Portlandicum	- U. Oolite. *Portland.*
	tricinctum	- L. Miocene.
Chemnitzia—Phasianella	- gigantea	- U. Oolite. *Kim. Clay.*
	lineata -	- L. Oolite. *Inf. Oo.*
	Heddingtonensis -	- } M. Oolite. *Cor. Oo.*
	striata -	- " "
	vittata -	- L. Oolite. *For. Marb.*
Chiton -	- Grayanus	- U. Silurian. *Wenlock.*
	Griffithii	- Silurian. *U. Llandovery.*
Columella -	- sulcata -	- O. Pliocene. *R. Crag.*
Conovulus -	- pyramidalis	- N. Pliocene.
Conus -	- deperditus	- M. Eocene.
	dormitor	- "
	sp. -	- L. Eocene.
Cyclonema -	- quadristriata	- Silurian. *U. Llandovery.*
	rupestris	- L. Silurian. *Bala.*
Cylindrites -	- acutus -	- L. Oolite. *Gt. Oo.*
Cypræa -	- Europæa	- O. Pliocene. *R. Crag.*
	lucida -	- N. Pliocene.
	oviformis	- L. Eocene.
Dentalium -	- ellipticum	- U. Cretaceous. *Gault.*
	striatum	- M. Eocene.
Euomphalus	- annulatus	- M. Devonian.
	carinatus	- U. Silurian. *Wenlock.*
	Corndensis	- L. Silurian. *Llandeilo.*
	discors -	- U. Silurian. *Wenlock.*
	funatus -	- Silurian. *Llandovery to Ludlow.*
	pentangulatus (*characteristic*) -	- } Carboniferous.
	Permianus (*characteristic*) -	- } M. Devonian. *Mag. L.*
	prænuntius	- Silurian. *U. Llandovery.*
	rugosus -	- U. Silurian. *Wenlock.*

Fusus - -	- antiquus	- O. N. and Post-Pliocene.
	contrarius = Trophon antiquum -	O. Pliocene. *R. Crag.*
	labiatus -	- U. Eocene.
	longevus	- M. Eocene.
	striatus	- U. Pliocene. *N. Crag.*
Helix -	- D'Urbani	- U. Eocene.
	labyrinthica	- U. Eocene.
	nemoralis	- Post-Pliocene.
	occlusa -	- U. Eocene.
Holopœa -	- concinna	- L. Silurian. *Bala.*
	corallii -	- U. Silurian. *Ludlow.*
Holopella -	- cancellata	- U. Silurian. *Bala to Ludlow.*
	plana -	- U. Silurian. *U. Llandovery.*
	tenuicincta	- " "
Hydrobia -	- Chastellii	- U. Eocene.
Littorina -	- littorea -	- N. and Post-Pliocene.
	rudis -	- Post-Pliocene.
Loxonema -	- fasciatum (*characteristic*)	M. Permian. *Mag. L.*
	Lefebvrei	- Carboniferous.
Lymnea -	- caudata -	- U. Eocene.
	longiscata	- M. Eocene.
	sp. -	- L. Miocene. *Hempstead.*
	sp. -	- U. Oolite. *Purbeck.*
Macrocheilus	- fusiformis	- Silurian. *U. Llandovery.*
	ovalis -	- Carboniferous.
	pusillus -	- "
	symmetricus (*characteristic*) - -	M. Permian. *Mag. L.*
	sp. -	- M. Devonian.
Melania -	- costata -	- L. Miocene. *Hempstead.*
	fasciata -	- "
	inquinata	- L. Eocene.
	muricata	- M. Eocene.
	turritissima	- U. Eocene.
	sp. -	- U. Oolite. *Purbeck.*
	sp. -	- L. Cretaceous. *Wealden.*
Melanopsis -	- harpæformis	- U. Oolite. *Purbeck.*
	sub-fusiformis	M. Eocene.
	tricarinata	- L. Cretaceous. *Wealden.*
	carinata -	- L. Miocene. *Hempstead.*
Mitra -	- scabra -	- M. and U. Eocene.

Murchisonia	angulata	U. Devonian.
	articulata	Silurian. *Llandovery and Ludlow.*
	Lloydii	U. Silurian. *Wenlock and Ludlow.*
	simplex	Silurian. *Bala and L. Llandovery.*
	spinosa	Devonian.
	sp.	Carboniferous.
Murex	asper	M. Eocene.
Nassa	monensis	N. Pliocene.
	reticosa	O. Pliocene. *R. Crag.*
Natica	affinis	Post-Pliocene.
	ambulacrum	M. Eocene.
	clausa	Post-Pliocene.
	elegans	U. Oolite. *Portland.*
	elliptica	Carboniferous.
	Gaultina	U. Cretaceous. *Gault.*
	Gentii	" *U. Gr.*
	helicoides	N. Pliocene.
	hemiclausa	O. Pliocene. *R. Crag.*
	Leibnitziana (*characteristic*)	M. Permian. *Mag. L.*
	parva	U. Silurian. *Ludlow.*
Nerinea	Goodhallii	M. Oolite. *Cor. Oo.*
	hieroglyphica	" "
	Voltzii	L. Oolite. *Gt. Oo.*
Nerita	costulata	L. Oolite. *Gt. Oo.*
Neritina	concava	U. Eocene.
	Fittoni	L Cretaceous. *Wealden.*
Neritoma	sinuosa	U. Oolite. *Portland.*
Oliva	Branderi	M. Eocene.
Ophileta	compacta	L. Silurian. *Llandeilo.*
Paludina	carinifera	U. Oolite. *Purbeck.*
	fluviorum	L. Cretaceous. *Wealden.*
	lenta	U. Eocene, L. Miocene, and N. Pliocene.
	orbicularis	U. Eocene.
	Sussexensis	L. Cretaceous. *Wealden.*
Patella	latissima	U. Oolite. *Kim. Clay.*
	mucronata	Carboniferous.
	rugosa	L. Oolite. *Gt. Oo.*
	sp.	O. Pliocene. *Wh. Crag.*
Phorus	agglutinans	M. Eocene.
	canaliculatus	U. Cretaceous. *L. Chalk.*
	extensus	L. Eocene.

Physa -	- Bristovii	- U. Oolite. *Purbeck.*
Planorbis -	- discus -	- U. Eocene.
	euomphalus	- M. Eocene.
	lens -	- L. Miocene. *Hempstead.*
	obtusus -	- U. Eocene.
Platyschisma	- helicites	- U. Silurian. *Ludlow and Downton.*
Pleurotoma	- attenuata	- M. Eocene.
	plebeia -	- U. Eocene.
Pleurotomaria	- Anglica -	- L. and M. Lias.
	antrina (*characteristic*) -	M. Permian. *Mag. L.*
	aspera -	- M. and U. Devonian.
	carinata -	- Carboniferous.
	elongata -	- L. Oolite. *Inf. Oo.*
	fissicarina	- Silurian. *U. Llandovery.*
	gigantea	- L. Cretaceous. *L. Gr.*
	granulata	- L. and M. Oolite. *Inf. Gt. and Cor. Oo.*
	ornata -	- L. Oolite. *Inf. Oo.*
	pallium -	- " "
	perspectiva	- U. Cretaceous. *U. Chalk.*
	reticulata	- U. Oolite. *Kim. Clay.*
	Rhodani	- U. Cretaceous. *Gault and U. Gr.*
	rugata -	- U. Oolite. *Portland.*
	undata -	- U. Silurian. *Ludlow.*
Potamides -	- concavus	- M. Eocene.
	cinctus -	- U. Eocene.
Pteroceas -	- Fittoni -	- L. Cretaceous. *L. Gr.*
Pupa - -	- muscorum	- Post-Pliocene.
Purpura -	- tetragona	- O. Pliocene. *R. Crag.*
Purpurina -	- nodulata	- L. and M. Oolite. *Gt. and Cor. Oo.*
Purpuroidea	- Morrissii	- L. Oolite. *Gt. Oo.*
Pyrula -	- reticulata	- O. Pliocene. *Wh. Crag.*
	Smithii -	- L. Eocene.
Raphistoma	- equale -	- L. Silurian. *Bala.*
	lenticularis	- " *U. Llandovery.*
Rimula=Emarginula -	- clathrata	- L. Oolite. *Gt. Oo.*
Rissoa -	- Chastellii	- U. Eocene and L. Miocene.
	parva -	- Post-Pliocene.
Rostellaria	- ampla -	- L. and U. Eocene.

Rostellaria -	- carinata -	- U. Cretaceous. *Gault.*
	Parkinsoni	- U. Cretaceous. *Gault and Blackdown.*
	rimosa -	- M. Eocene.
Scalaria -	- Bowerbankii	- L. Eocene.
	Gaultina	- U. Cretaceous. *Gault.*
	Grænlandica	- O. N. and Post-Pliocene (*living*).
Solarium -	- conoideum	- U. Cretaceous. *Gault.*
	canaliculatum	- M. Eocene.
	ornatum	- U. Cretaceous. *Gault and U. Gr.*
Strombus -	- Bartonensis	- M. Eocene.
Succinea -	- elongata	- Post-Pliocene.
Terebellum -	- fusiforme	- M. and U. Eocene.
	sopita -	- U. Eocene.
Tritonium	- carinatum	- N. Pliocene.
Trochella -	- prisca -	- Carboniferous.
Trochonema	- tricincta -	- Silurian. *U. Llandovery.*
Trochotoma	- annuloides	- L. Oolite. *Gt. Oo.*
Trochus -	- monilifer	- M. Eocene.
Trophon -	- antiquum = Fusus contrarius-	- O. Pliocene. *R. Crag.*
	clathratum	- Post-Pliocene.
	subnodosum	- L. Eocene.
Turritella -	- communis	- N. Pliocene. *N. Crag.*
	concava	- U. Oolite. *Portland.*
	granulata	- U. Cretaceous. *U. Gr.*
	incrassata	- N. Pliocene.
	imbricataria	- M. Eocene.
Typhis -	- pungens -	- M. and U. Eocene.
Valvata -	- sp. -	- U. Oolite. *Purbeck.*
Vicarya -	- Lujani -	- L. Cretaceous. *Punfield.*
Voluta -	- ambigua -	- U. Eocene.
	athleta -	- M. and U. Eocene.
	Lamberti	- O. Pliocene. *Wh. and R. Crag.*
	luctatrix -	- M. Eocene.
	nodosa -	- L. Eocene.
	Rathieri	- L. Miocene.
	scabricula	- M. Eocene.
	Selseiensis	- "
	Wetherellii	- L. Eocene.

HETEROPODA=NUCLEOBRANCHIATA.

Bellerophon (*Genus occurs only up to Carboniferous*) -	- acutus -	- L. Silurian. *Llandeilo.*
	bilobatus	- ,,
	bisulcatus	- L. M. and U. Devonian.
	costatus -	- Carboniferous.
	dilatatus	- Silurian. *Bala to Wenlock.*
	expansus	- Silurian. *Llandovery and Ludlow.*
	hiulcus -	- Carboniferous.
	nodosus -	- L. Silurian. *Bala.*
	subglobatus	- M. and U. Devonian.
	tangentialis	- Carboniferous.
	trilobatus	- U. Silurian. *Ludlow and Downton.*
	Wenlockensis	- U. Silurian. *Wenlock.*
	sp. -	- U. Cambrian. *Tremadoc. slates.*
Maclurea -	- Logani -	- L. Silurian. *Llandeilo.*
	Peachii -	- ,, ,,
Porcellia -	- Puzio -	- Carboniferous.

HYDROZOA.

Didymograpsus	- caduceus	- L. Silurian. *Bala.*
	geminus	- ,, *Stiper-Stones.*
	Murchisonii	- ,, *Llandeilo.*
Diplograpsus	- bullatus	- L. Silurian. *Bala.*
	folium -	- ,, *Llandeilo.*
	pristis -	- ,, ,,
Graptolithus	- Conybeari	- L. Silurian. *Bala.*
	Flemingii, and 4 other species	U. Silurian. *Wenlock.*
	Hisingeri= sagittariius -	L. Silurian. *Llandeilo.*
	priodon -	- Silurian. *Bala to Ludlow.*
Rastrites -	- peregrinus	- L. Silurian. *Llandeilo and Bala.*

Insecta.

Æshna -	- perampla	- U. Oolite. *Purbeck.*
Bupreston -	- stygnus	- U. Oolite. *Purbeck.*
Carabus -	- elongatus	- U. Oolite. *Purbeck.*
	sp. -	- Lias.
Corydalis -	- sp. -	- Carboniferous.
Elater -	- sp. -	- Lias.
Ephemera -	- sp. -	- Lias.
Gryllus -	- sp. -	- Lias.
Hemerobius	- sp. -	- Lias.
Libullela -	- Hopei -	- Lias.

Lamellibranchiata=Conchifera.

Anatina -	- undata -	- L. and M. Oolite. *Gt. and Cor. Oo.*
	undulata	- M. Oolite. *Oxf. Clay.*
Anodonta -	- Jukesii -	- U. Old Red.
Anodontopsis	- several species-	U. Silurian. *Ludlow.*
Arca - -	- æmula -	- L. and M. Oolite. *Gt. and Cor. Oo.*
	Branderi	- M. Eocene.
	carinata	- U. Cretaceous. *U. Gr.*
	Hirsonensis	- L. Oolite. *Gt. Oo.*
	sp. -	- M. Permian. *Mag. L.*
Artemis -	- lentiformis	- O. Pliocene. *R. Crag.*
Astarte -	- Beaumontii	- L. Cretaceous. *L. Gr.*
	borealis=compressa -	N. and Post-Pliocene.
	cuneata	- U. Oolite. *Portland.*
	elegans	- L. Oolite. *Inf. Oo.*
	Hartwelliensis	U. Oolite. *Kim. Clay.*
	lurida -	- M. Oolite. *Oxf. Clay.*
	mutabilis	- N. Pliocene.
	obliquata	- O. Pliocene.
	Omalii	- "
	ovata -	- M. and U. Oolite.
	sulcata -	- Post-Pliocene.
Avicula -	- contcrta (*characteristic*) -	Trias. *Penarth.*
	cygnipes	- L. and M. Lias.
	Damnoniensis -	U. Devonian.
	Danbyi	- U. Silurian. *Ludlow.*

Avicula -	decussata *(characteristic)* -	Trias. *Penarth.*
	echinata -	L. Oolite. *Cornbrash.*
	gryphæoides -	U. Cretaceous. *Gault to Ch. Marl.*
	inæquivalvis -	L. Lias.
	speluncaria *(characteristic)*	M. Permian. *Mag. L.*
	subradiata -	M. and U. Devonian.
	sp. - -	Carboniferous.
	sp. - -	U. Oolite. *Purbeck.*
Aviculopecten -	papyraceus -	Carboniferous.
	sublobatus -	"
Axinus -	obscurus *(characteristic)* -	M. Permian. *Mag. L.*
	truncatus *(characteristic)*	" "
Bakevellia -	antiqua *(characteristic)* -	M. Permian. *Mag. L.*
Cardinia -	Listeri - -	L. and M. Lias.
Cardiola -	fibrosa - -	U. Silurian. *Wenlock and Ludlow.*
Cardiomorpha -	modioliformis *(characteristic)*	M. Permian. *Mag. L.*
	oblonga - -	Carboniferous.
Cardita=Venericardia -	analis - -	N. Pliocene.
	planicosta -	M. Eocene.
	senilis - -	O. Pliocene. *Wh. and R. Crag.*
	sulcata - -	U. Eocene.
Cardium -	augustatum -	O. Pliocene. *R. Crag.*
	dissimile -	U. Oolite. *Portland.*
	edule - -	N. Pliocene. *N. Crag.*
	fasciatum -	Post-Pliocene.
	Grænlandicum	N. Pliocene.
	Hillanum -	U. Cretaceous. *U. Gr.*
	Rhæticum *(characteristic)*	Trias. *Penarth.*
	sphæroidium -	L. Cretaceous. *L. Gr.*
	striatulum -	L. and U. Oolite. *Gt. Oo. and Kim. Clay.*
Ceromya -	concentrica -	L. Oolite. *For. Marb.*
Chama -	squamosa -	M. and U. Eocene.
Coralliophaga -	cyprinoides -	O. Pliocene. *Wh. Crag.*
Corbula -	alata - -	L. Cretaceous. *Wealden.*

Corbula -	- longirostris	- L. Eocene.
	pisum -	- M. and U. Eocene and L. Miocene.
	Vectensis	- U. Eocene.
	sp. -	- U. Oolite. *Purbeck.*
	sp. -	- L. Cretaceous. *Punfield.*
Crassatella -	- sulcata -	- M. and U. Eocene.
Crenella -	- lævigata	- Post-Pliocene.
	nigra -	- ,,
Cryptodon -	- angulatum	- L. Eocene.
Ctenodonta -	- Anglica	- Silurian. *Llandovery to Ludlow.*
	deltoidea	- Silurian. *U. Llandovery.*
	Eastnori	- ,, ,,
	lingualis	- ,, ,,
	semitruncata	- L. Silurian. *Bala.*
Cucullella -	- amygdalina	- M. and U. Devonian.
	Cawdori	- U. Silurian. *Ludlow.*
	Hardringii	- U. Devonian.
Cucullæa -	- costellata	- L. Cretaceous. *L. Gr.*
	elongata	- L. and M. Oolite. *Gt. and Cor. Oo.*
	fibrosa	- U. Cretaceous. *U. Gr.*
	oblonga	- L. and M. Oolite. *Gt. and Cor. Oo.*
Cyclas -	- elongata	- L. Cretaceous. *Wealden.*
	media -	- ,, ,,
	parva -	- U. Oolite. *Purbeck.*
Cyrena -	- cuneiformis	- L. Eocene.
	elongata	- U. Oolite. *Purbeck.*
	fluminalis	- Post-Pliocene.
	major	- L. Cretaceous. *Wealden.*
	media	- ,, ,,
	obovata	- U. Eocene.
	pulchra	- ,,
	semistriata	- U. Eocene and L. Miocene.
	tellinella	- L. Eocene.
Cyprina -	- Islandica	- N. and Post-Pliocene.
	Morrisii	- L. Eocene.
	planata	- ,,
	rustica	- O. Pliocene.
Cytherea -	- parva -	- L. Cretaceous. *L. Gr.*
	incrassata	- M. and U. Eocene.
Exogyra -	- columba	- U. Cretaceous. *U. Gr.*
	conica -	- ,, *U. Chalk.*
	sinuata	- L. Cretaceous. *L. Gr.*

Gervillia -	- anceps -	- L. Cretaceous. *L. Gr.*
	aviculoides	- M. and U. Oolite.
	lanceolata	- L. Oolite. *Gt. Oo.*
	siliqua -	- L. and M. Oolite. *Gt. and Cor. Oo.*
Goniomya -	- literata -	- L. and M. Oolite. *Gt. and Cor. Oo.*
	scripta -	- L. and M. Oolite. *Gt. and Cor. Oo.*
Grammysia -	- cingulata	U. Silurian. *U. Ludlow.*
Gresslya -	- abducta	- L. Oolite. *Inf. Oo.*
	peregrina	- " *For. Marb.*
Gryphæa -	- convexa= Ostrea vesicularis -	U. Cretaceous. *U. Chalk.*
	dilatata	- M. Oolite. *Oxf. Clay.*
	incurva	- L. Lias.
	nana -	- M. and U. Oolite.
	vesiculosa	- U. Cretaceous. *U. Gr.*
	virgula	- U. Oolite. *Kim. Clay.*
Hippopodium	- ponderosum	- L. Lias.
Inoceramus	- Brongniarti	- U. Cretaceous. *U. Chalk.*
	concentricus	- " *Gault.*
	Lamarckii	- " *U. Chalk.*
	mytiloides	- " *L. Chalk.*
	sulcatus	- " *Gault.*
Isocardia -	- minima -	- L. Oolite. *For. Marb.*
	tenera -	- L. and M. Oolite. *Gt. and Cor. Oo.*
Isodonta -	- triangularis	- L. and M. Oolite. *Gt. and Cor. Oo.*
Leda -	- amygdaloides	- L. Eocene.
	limatula -	- N. Pliocene.
	pernula -	- Post-Pliocene.
	pygmea -	- "
	truncata	- "
Lima=Plagiostoma -	- cardiiformis	- L. Oolite. *Gt. Oo.*
	duplicata	- L. and M. Oolite. *Gt. and Cor. Oo.*
	gigantea	- L. Lias.
	globosa -	- U. Cretaceous. *L. Chalk and Marl.*
	Hoperi -	- U. Cretaceous. *U. Chalk.*

Lima=Plagiostoma -	- obliquata	- U. Oolite. *Portland.*
	pectiniformis	- L. Oolite. *Inf. Oo.*
	rigida -	- „ *Cor. Oo.*
	rigidula -	- „ *For. Marb.*
	rustica	- M. and U. Oolite.
Lithodomus, *sub-genus of* Modiola -	- inclusus	- L. to U. Oolite.
	sp. -	- Carboniferous.
Lucina -	- crassa -	- L. and M. Oolite. *Gt. and Cor. Oo.*
	Portlandica	- U. Oolite. *Portland.*
	tenera -	- U. Cretaceous. *Gault.*
Lyrodeama	- cuneata -	- Silurian. *U. Llandovery.*
Megalodon	- cucullatus	- M. Devonian.
Modiola -	- bipartita	- L. and M. Oolite. *For. Marb. and Oxf. Clay.*
	cuneata -	- Lias to M. Oolite.
	minima (*characteristic*) -	Trias. *Penarth.*
	pallida	- U. Oolite. *Portland.*
	sp. -	- „ *Purbeck.*
	scalprum	- M. Lias.
Modiolopsis	- antiqua	- U. Silurian. *Wenlock.*
	complanata	- „ *Ludlow.*
	expansa -	- L. Silurian. *Bala.*
	platyphilla	- U. Silurian. *Ludlow.*
Monotis -	- decussata	- L. Lias.
Mya -	- arenaria	- N. Pliocene.
	truncata	- Post-Pliocene.
Myacites -	- calceiformis	- L. and M. Oolite. *Gt. and Cor. Oo.*
	decurtata	- L. Oolite. *For. Marb.*
	mandibula	- L. Cretaceous. *L. Gr.*
	recurva	- M. Oolite. *Oxf. Clay.*
	securiformis	- L. Oolite. *For. Marb.*
Mytilus -	- affinis -	- U. Eocene.
	Chemungensis	- U. Silurian. *Wenlock.*
	edulis -	- Post-Pliocene.
	Lyellii -	- L. Cretaceous. *Wealden.*
	septifer (*characteristic*) -	M. Permian.
Nucula -	- Bowerbankii	- L. Eocene.
	Cobboldiæ	- O. and N. Pliocene.

Nucula	nucleus	Post-Pliocene.
	pectinata	U. Cretaceous. *Gault.*
	similis	U. Eocene.
	sp.	Carboniferous.
Orthonota	nasuta	L. Silurian. *Bala.*
	several species	U. Silurian. *Ludlow.*
Ostrea	acuminata	L. Oolite. *Fuller's Earth.*
	Bellovacina	L. Eocene.
	carinata	L. Cretaceous. *L. Gr.*
	cyathula	L. Miocene.
	deltoidea	U. Oolite. *Kim. Clay.*
	distorta	„ *Purbeck.*
	expansa	„ *Portland.*
	flabelloides	L. Oolite. *Inf. Oo.*
	flabellula	M. Eocene.
	frons	U. Cretaceous. *L. Chalk.*
	gregaria	M. Oolite. *Cor. Oo.*
	intusstriata (*characteristic*)	Trias. *Penarth.*
	Liassica (*characteristic*)	Trias and L. Lias. *Penarth.*
	Marshii	L. and M. Oolite.
	princeps	O. Pliocene. *Wh. and R Crag.*
	solitaria	M. and U. Oolite. *Cor. ana Portland Oo.*
	undosa	M. Oolite. *Oxf. Clay.*
	Vectensis	U. Eocene.
	vesicularis = Gryphæa convexa	U. Cretaceous. *U. Chalk.*
Pachyrisma	grande	L. Oolite. *Gt. Oo.*
Palæarca	amygdalis	L. Silurian. *Llandeilo.*
	socialis	„ „
	sp.	U. Silurian. *Ludlow.*
Panopæa	Norwegica	N. and Post-Pliocene.
Pecten	annulatus	L. and M. Oolite. *Gt. and Cor. Oo.*
	arcuatus	L. and U. Oolite. *Gt. and Portland Oo.*
	asper	U. Cretaceous. *U. Gr.*
	Beaveri	U. Cretaceous. *L. Ch. and Marl.*
	cinctus = crassitesta	L. Cretaceous. *L. and M Neocomian.*

Pecten	demissus	L. and M. Oolite. *Gt. and Cor. Oo.*
	dentatus	L. Oolite. *Inf. Oo.*
	fibrosus	L. Oolite. *For. Marb.*
	Gerardi	O. Pliocene. *Wh. Crag.*
	Grænlandicus	Post-Pliocene.
	Islandicus	"
	lamellosus	U. Oolite. *Portland.*
	Liassicus	M. Lias.
	nitidus	U. Cretaceous. *U. Chalk.*
	orbicularis	U. Cretaceous. *Gault to Ch. Marl.*
	plebeius	O. Pliocene. *R. Crag.*
	quinquecostatus	U. Cretaceous. *U. Gr.*
	Valoniensis (*characteristic*)	Trias. *Penarth.*
	vimineus	M. Oolite. *Cor. Oo.*
Pectunculus	sublævis	U. Cretaceous. *U. Gr.*
	variabilis	O. Pliocene. *R. Crag.*
Perna	Mulleti	L. Cretaceous. *L. Gr.*
	quadrata	U. Oolite.
Pholadomya	acuticosta	L. Oolite. *Gt. Oo.*
	ambigua	L. M. and U. Lias.
	cuneata	L. Eocene.
	decussata	U. Cretaceous. *L. Chalk.*
	deltoidea	L. Oolite. *For. Marb.*
	equalis	M. Oolite. *Cor. Oo.*
	fidicula	L. Oolite. *Inf. Oo.*
	lyrata	" *For. Marb.*
	margaritacea	L. Eocene.
	ovalis	L. to U. Oolite.
Pholas	crispata	N. Pliocene.
Pinna	affinis	L. Eocene.
	granulata	U. Oolite. *Kim. Clay.*
	lanceolata	L. and M. Oolite. *Gt. Oo. and Cor. Oo.*
	mitis	L. and M. Oolite. *Gt. Oo. and Cor. Oo.*
Pleurophorus	costatus (*characteristic*)	M. Permian. *Mag. L.*
Pleurorhynchus = Conocardium	equicostatus	U. Silurian. *Wenlock.*
	Hibernicus	Carboniferous.
	pristis	Silurian. *U. Llandovery.*
Plicatula	inflata	U. Cretaceous. *L. Chalk.*

Plicatula	pectinoides	U. Cretaceous. *Gault.*
Posidonomya	Becheri	Carboniferous.
Potamomya	gregaria	M. Eocene.
	plana	U. Eocene.
Pterinea	bullata	Silurian. *U. Llandovery.*
	retroflexa	Silurian. *L. Llandovery to Ludlow.*
	sublævis	Silurian. *U. Llandovery.*
Pteroperna	costatula	L. Oolite. *Gt. Oo.*
Pullastra	arenicola (*characteristic*)	Trias. *Penarth.*
Quenstedtia	lævigata	L. and M. Oolite. *Gt. and Cor. Oo.*
Radiolites	Mortoni	U. Cretaceous. *L. Chalk.*
Saxicava	Arctica	Post-Pliocene.
	rugosa	"
Schizodus	Schlotheimi (*characteristic*)	M. Permian. *Mag. L.*
	truncatus	"
Sphæra	corrugata	L. Cretaceous. *L. Gr.*
Spondylus	spinosus	U. Cretaceous. *U. Chalk.*
	gibbosus	U. Cretaceous. *Gault.*
	striatus	" *L. Chalk.*
Syndosmya	splendens	L. Eocene.
Tellina	balthica=solidula	N. Pliocene.
	calcarea=proxima	Post-Pliocene.
	obliqua	N. Pliocene.
Tellinites	affinis	U. Silurian. *Downton.*
Teredo	antenautæ	L. Eocene.
Thetis	major	L. and U. Cretaceous. *L. and U. Gr.*
	minor	L. Cretaceous. *L. Gr.*
Thracia	depressa	U. Oolite. *Kim. Clay.*
	myopsis	Post-Pliocene.
Trigonia	caudata	L. Cretaceous. *L. Gr.*
	clavellata	M. and U. Oolite. *Cor. Oo. and Kim. Clay.*
	costata	L. to U. Oolite.
	dœdalia	L. and U. Cretaceous. *L. and U. Gr.*
	gibbosa	U. Oolite. *Portland.*
	Goldfussii	L. Oolite. *Gt. Oo.*
	impressa	" "
	incurva	U. Oolite. *Portland.*

Unio - -	- compressus	- U. Oolite. *Purbeck.*
	Gibbsii -	- L. Miocene.
	littoralis	- Post-Pliocene.
	Mantellii	- L. Cretaceous. *Wealden.*
	solandri	- U. Eocene.
	Valdensis	- L. Cretaceous. *Wealden.*
Venus -	- incrassata	- U. Eocene.

MAMMALIA.

Amphitherium	- Broderipii	- L. Oolite. *Stonesfield Slate.*
	Prevostii	- " "
Anoplotherium	- commune	- U. Eocene.
	secundarium	- "
Anthracotherium	- sp. -	- U. Eocene.
Arvicola - -	- pratensis	- Post-Pliocene.
	sp. -	- N. Pliocene.
Balænodon -	- emarginatus (*ear-bones*) -	O. Pliocene. *R. Crag.*
Bos - -	- primigenius	- Post-Pliocene.
Cervus -	- anoceros	- O. Pliocene. *R. Crag.*
	megaceros = Megaceros Hibernicus -	N. and Post-Pliocene.
	tarandus	- Post-Pliocene.
Chæropotamus	- Cuvieri -	- U. Eocene.
Coryphodon	- Eocenus -	- L. Eocene.
Dichobune -	- cervinum	- U. Eocene.
Dichodon -	- cuspidatus	- M. and U. Eocene.
Didelphys -	- Colchesteri	- L. Eocene.
Elephas -	- antiquus	- N. Pliocene.
	meridionalis	- "
	primigenius	- Post-Pliocene.
Equus -	- fossilis -	- N. Pliocene.
Felis - -	- pardoides	- O. Pliocene. *R. Crag.*
	spelæa -	- Post-Pliocene.
Galestes -	- sp. -	- U. Oolite. *Purbeck.*
Hippopotamus	- major -	- N. Pliocene.
Hyæna -	- spelæa -	- Post-Pliocene.
Hyænodon -	- sp. -	- U. Eocene.
Hyracotherium	- leporinum	- L. Eocene.
Hyopatmus -	- bovinus -	- U. Eocene and L. Miocene.
	Vectensis	- U. Eocene.
Lophiodon	- minimus	- M. Eocene.
	sp. -	- L. Eocene.

Macacus -	- Eocenus	- L. Eocene.
Mastodon -	- Arvernensis = angustidens-	O. and N. Pliocene.
Microchærus	- erinaceus	- M. Eocene.
Microlestes -	- antiquus	- Trias. *Penarth.*
Ovibos -	- moschatus	- Post-Pliocene.
Paloplotherium	- annectens	- M. Eocene.
Palæotherium	- crassum -	- U. Eocene.
	curtum -	- "
	magnum-	- "
	medium -	- "
	minimum	- "
	minus -	- "
Phascolotherium -	Bucklandi	- L. Oolite. *Stonesfield Slate.*
Plagiaulax -	- Becklesii	- U. Oolite. *Purbeck.*
Pliolophus	- vulpiceps	- L. Eocene.
Rhinoceros -	- etruscus	- N. Pliocene.
	leptorhinus = megarhinus -	N. and Post-Pliocene.
	Schleiermach-eri -	- O. Pliocene. *R. Crag.*
	tichorhinus	- Post-Pliocene.
Spalacodon -	- sp. -	- U. Eocene.
Spalacotherium	- Brodiei -	- U. Oolite. *Purbeck.*
Stereognathus	- Ooliticus	- L. Oolite. *Stonesfield Slate.*
Tapirus -	- priscus -	- O. Pliocene. *R. Crag.*
Triconodon -	- sp. -	- U. Oolite. *Purbeck.*
Ursus -	- Arvenensis	- N. Pliocene.
	spelæus -	- Post-Pliocene.

PISCES.

Acanthoides	- sp. -	- M. Old Red.
Acrodus -	- acutus (*characteristic* -	Trias. *Penarth.*
	minimus (*characteristic* -	" "
	nobilis -	- L. Lias.
Acrolepis -	- Sedgwickii (*characteristic*) -	- M. Permian. *Marl-Slate.*
Æchmodus (*Genus Liassic*)	- Leachii -	- L. Lias.
Aspidorhynchus	- euodus -	- M. Oolite. *Oxf. Clay.*
	Fisheri -	- U. Oolite. *Purbeck.*
Asteracanthus	- acutus -	- L. Oolite. *For. Marb.*

Asteracanthus -	granulosus -	L. Cretaceous. *Wealden.*
	ornatissimus -	U. Oolite. *Kim. Clay.*
	semisulcatus -	L. Oolite. *Gt. Oo.*
Asterolepis -	sp. -	U. Old Red.
Auchenaspis -	ornatus -	U. Silurian. *Downton.*
	Salteri -	" "
Beryx - -	Lewesiensis -	U. Cretaceous. *U. Chalk.*
Carcharodon -	angustidens -	M. Eocene.
Cardiodon -	rugulosus -	L. Oolite. *For. Marb.*
Caturus -	angustus -	U. Oolite. *Portland.*
Cephalaspis -	Lyelli -	L. Old Red.
	Murchisonii -	U. Silurian. *Downton.*
Ceratodus -	altus (*characteristic*) -	Trias. *Penarth.*
Cheiracanthus -	sp. -	M. Old Red.
Cheirolepis -	sp. -	M. Old Red.
Cladodus -	striatus -	Carboniferous.
Cochliodus -	contortus -	Carboniferous.
Cocosteus -	decipiens -	U. Old Red.
	sp. -	M. Old Red.
Cœlacanthus -	granulatus (*characteristic* -	M. Permian. *Marl-Slate.*
Cœlopoma -	Colei -	L. Eocene.
Ctenacanthus -	brevis -	Carboniferous.
Ctenodus -	sp. -	M. Old Red.
Dapedius -	monilifer -	Lias.
	politus -	L. Lias.
Dendrodus -	sp. -	M. Old Red.
Diplacanthus -	sp. -	M. Old Red.
Diplodus -	gibbosus -	Carboniferous.
Diplopterus -	sp. -	M. Old Red.
Dipteronotus -	cyphus -	Trias.
Dipterus -	sp. -	M. Old Red.
Edaphodon -	Bucklandi -	M. Eocene.
	Sedgwickii -	U. Cretaceous. *U. Gr.*
Galeocerdo -	latidens -	M. Eocene.
Glyptolepis -	sp. -	M. and U. Old Red.
Glyptopomus -	sp. -	U. Old Red.
Gyrodus -	Cuvieri -	M. Oolite. *Cor. Oo.*
	Mantellii -	L. Cretaceous. *Wealden.*
Gyrolepis -	tenuistriatus -	Trias. *Penarth.*
Holoptychius -	nobilissimus -	U. Old Red.
	Portlockii -	Carboniferous.
Hybodus -	acutus -	U. Oolite. *Kim. Clay.*
	Keuperinus -	Trias.

Hybodus -	- minor (*characteristic* -	Trias. *Penarth.*
	obtusus -	- M. Oolite. *Oxf. Clay.*
	plicatilis	- Trias. *Penarth.*
	reticulatus	- L. Lias.
	strictus -	- U. Oolite. *Portland.*
	subcarinatus	- L. Cretaceous. *Wealden.*
Ischyodus -	- Townshendi	- U. Oolite. *Portland.*
Lamna -	- acuminata	- U. Cretaceous. *U. Chalk.*
	elegans -	- L. and M. Eocene.
Lepidosteus	- sp. -	- U. Eocene.
Lepidotus -	- Fittoni -	- L. Cretaceous. *Wealden.*
	gigas -	- Lias.
	macrocheirus	- M. Oolite. *Oxf. Clay.*
	Mantellii	- U. Oolite and L. Cretaceous.
Leptolepis -	- macrophthalmus -	- M. Oolite. *Oxf. Clay.*
Macropoma -	- Mantellii	- U. Cretaceous. *U. Chalk.*
Megalichthys	- Hibberti (*characteristic* -	Carboniferous.
Microdon -	- radiatus -	- U. Oolite. *Purbeck.*
Myliobates -	- Edwardsii	- M. Eocene.
Nemacanthus	- monilifer (*characteristic* -	Trias. *Penarth.*
Odontacanthus	- sp. -	- M. Old Red.
Onchus -	- Murchisonii	- U. Silurian. *Ludlow and Downton.*
	tenuistriatus	- U. Silurian. *Ludlow.*
	arcuatus	- M. Old Red.
	sp. -	- Carboniferous.
Ophiopsis -	- breviceps	- U. Oolite. *Purbeck.*
Orocanthus -	- sp. -	- Carboniferous.
Orodus -	- ramosus -	- Carboniferous.
Osmeroides -	- Lewesiensis	- U. Cretaceous. *U. Chalk.*
Osteolepis -	- major -	- M. Old Red.
Ostraceon -	- sp. -	- M. Eocene.
Otodus -	- appendiculatus -	U. Cretaceous. *Gault to U. Chalk.*
	obliquus	- L. and M. Eocene.
Palæoniscus	- comptus (*characteristic*) -	M. Permian. *Marl-slate.*
	elegans (*characteristic* -	" "
	glaphyrus (*characteristic*) - -	" "

Petalodus -	- Hastingsiæ	- Carboniferous.
Pholidophorus	- Flesheri -	- L. Oolite. *Inf. Oo.*
	minor -	- ,, *Gt. Oo.*
	ornatus -	- U. Oolite. *Purbeck.*
Platygnathus	- sp. -	- M. Old Red.
Platysomus -	- macrurus (*characteristic* -	- M. Permian. *Marl-slate.*
	striatus (*characteristic*) -	,, *Mag. L.*
Plectrodus -	- mirabilis	- U. Silurian. *Ludlow and Downton.*
	pustuliferus	- U. Silurian. *Ludlow.*
Pæcilodus -	- Jonesii -	- Carboniferous.
Pristis -	- bisulcatus	- L. Eocene.
Psammodus	- porosus -	- Carboniferous.
Pteraspis -	- Banksii -	- U. Silurian. *Ludlow and Downton.*
	Ludensis	- U. Silurian. *Ludlow and Downton.*
	truncatus	- U. Silurian. *Ludlow and Downton.*
	Lloydii -	- L. Old Red.
Pterichthys	- latus -	- Old Red.
	major -	- M. Old Red.
Ptychodus -	- decurrens	- U. Cretaceous. *L. Chalk.*
Pycnodus -	- Mantellii	- L. Cretaceous. *Wealden.*
Pygopterus -	- mandibularis (*characteristic* -	- M. Permian. *Marl-slate.*
Rhizodus -	- Hibberti	- Carboniferous.
	Portlockii	- ,,
Saurichthys	- apicalis (*characteristic*) -	Trias. *Penarth.*
Sphagodus -	- pristodontus	- U. Silurian. *Ludlow.*
Sphærodus -	- gigas -	- U. Oolite. *Kim. Clay.*
Strophodus -	- magnus	- L. Oolite. *Gt. Oo.*
	subreticulatus	,, *Inf. Oo.*
Tetrapterus	- priscus -	- L. Eocene.

Plants.

Abietites -	- Benstedi	- L. Cretaceous. *L. Gr.*
Adiantites -	- Hibernicus	- U. Devonian.
Alethopteris	- lonchitica	- Carboniferous.
	sp. -	- Permian.

Alnites	Macquarii	L. Miocene.
Andromeda	reticulata	L. Miocene.
Annularia	sphenophylloides	Carboniferous.
Aralia	primigenia	M. Eocene.
Araucaria	sphærocarpa	L. Oolite. *Inf. Oo.*
Aroides	Stutterdi	,, *Stonesfield Slate.*
Asterophyllites	foliosus	Carboniferous.
	grandis	,,
Betula	nana	Post-Pliocene.
Calamites	cannæformis	Carboniferous.
	Sucowii	Permian
Cardiocarpum	anomalum	Carboniferous.
Carpolithes	Bucklandi	M. Oolite. *Cor. Oo.*
	conicus	,, ,,
	Websteri	L. Miocene.
Caulerpites	selaginoides (*characteristic*)	M. Permian. *Marl-slate.*
Chara	helicteres	L. Miocene.
	Lyellii	M. Eocene.
	medicaginula	L. Miocene.
	tuberculata	U. Eocene.
Clathraria	Lyellii	L. and U. Cretaceous. *Weald. and Ch. M.*
Comptonia	dryandrifolia	M. Eocene.
Corylus	grosse-dentata	Miocene.
Cruziana	semiplicata	U. Cambrian. *Lingula flags.*
Cycadeoidea	megaphylla	U. Oolite. *Purbeck.*
	microphylla	,, ,,
Cyclopteris	Hibernica	U. Old Red.
	dilatata	Carboniferous.
Cyclostigma	(*sub-genus of* Lepidodendron)	U. Old Red.
Dammarites	Fittoni	U. Oolite. *Purbeck.*
Dadoxylon	medullare	Carboniferous.
Daphnogene	Veronensis	M. Eocene.
Endogenites	erosa	L. Cretaceous. *Wealden.*
Equisetites	Brodiei	L. Lias.
	sp.	Carboniferous.
Equisetum	columnare	L. Oolite. *Inf. Oo. and Gt. Oo.* and Trias. *Keuper.*
	Lyellii	L. Cretaceous. *Wealden.*
Ficus	granadilla	M. Eocene.
Fillicites	Hebridica	Miocene.

Flabellaria -	- Lamanonis	- U. Eocene.
Glossopteris=Sagenopteris	- *genus* -	- Oolitic.
Hemitelites	- Brownii=Phlebopteris contigua -	Carboniferous to Oolite.
Hightia -	- elegans -	- L. Eocene.
Kaidacarpum	- Ooliticum	- L. Oolite. *Gt. Oo.*
Knorria -	- dichotoma	- U. Devonian.
Leguminosites	- several species	L. Eocene.
Lepidodendron	- elegans -	- Carboniferous.
	elongatum	- Permian.
	Sternbergii	- Carboniferous.
Lepidostrobus	- ornatus -	- Carboniferous.
	variabilis	- ,,
Lonchopteris	- Mantellii	- L. Cretaceous. *Wealden.*
Lycopodites	- sp. -	- Old Red.
Mantellia -	- nidiformis	- U. Oolite. *L. Purbeck.*
Nelumbium	- Doris -	- L. Miocene.
Neuropteris	- gigantea	- Carboniferous.
	Huttoniana (*characteristic* - -	M. Permian. *Marl-slate.*
Nipadites -	- ellipticus	- L. Eocene.
	umbonatus	- ,,
Nullipora -	- polymorpha	- Post-Pliocene.
Otopteris -	- *genus* -	- Oolitic.
	obtusa -	- L. Lias.
Pachypteris	- *genus* -	- Oolitic.
Palæozamia	- *genus* -	- Oolitic.
	Bechei -	- L Lias.
	Bucklandi	- ,,
Pecopteris -	- aquilina	- Carboniferous.
Petrophiloides	- Richardsoni	- L. Eocene.
Phlebopteris	- contigua=Hemitelites Brownii -	Carboniferous to Oolite.
Pinites -	- Dunkeri	- L. Cretaceous. *Wealden.*
	elongatus	- L. Oolite. *Lias.*
	Eggensis	- Miocene.
Podocarya -	- Bucklandi	- L. Oolite. *Inf. Oo.*
Pothocites -	- Grantonii	- Carboniferous.
Pterophyllum	- *genus* -	- Mesozoic.
	comptum	- L. Oolite. *Gt. Oo.*
Rhamnites	- multinervatus	- Miocene.
Sagenopteris=Glossopteris	- *genus* -	- Oolitic.

Sequoiea -	- Couttsiæ	- L. Miocene.
	Langsdorfii	- Miocene.
Sigillaria -	- lævigata	- Carboniferous.
	reniformis	- "
Sphenophyllum	- erosum -	- Carboniferous.
Sphenopteris	- gracilis -	- L. Cretaceous. *Wealden.*
	latifolia -	- Carboniferous.
	sp. -	- L. Oolite.
Stigmaria -	- ficoides -	- Carboniferous.
Thuytes -	- *genus* -	- Mesozoic.
	expansus	- L. Oolite. *Gt. Oo.*
	Kurrianus	- L. Cretaceous. *Wealden.*
Tæniopteris	- *genus* -	- Oolitic.
	latifolia	- L. Oolite. *Gt. Oo.*
	vittata	- " "
Trigonocarpum	- olivæforme	- Carboniferous.
	ovatum	- "
Ullmania -	- sp. -	- Carboniferous.
	sp. -	- Permian.
Voltzia -	- Phillipsii (*characteristic*) -	M. Permian. *Mag. L.*
Walchia -	- piniformis	- Permian.
Wetherellia	- variabilis	- L. Eocene.
Zamia -	- *genus* -	- Oolitic.
	gigas -	- L. Oolite. *Inf. Oo.*

POLYZOA.

Cellepora -	- cellulosa	- O. Pliocene. *Wh. Crag.*
	favosa -	- U. Silurian. *Wenlock.*
Ceriopora -	- affinis -	- U. Silurian. *Wenlock.*
Crisia -	- eburnea	- Post-Pliocene.
Diastopora -	- diluviana	- L. Oolite. *For. Marb.*
Discopora -	- antiqua -	- U. Silurian. *Wenlock.*
Eschara -	- Brongniarti	- L. Eocene.
	disticha -	- U. Cretaceous. *Chalk.*
Escharina -	- oceani -	- U. Cretaceous. *Chalk.*
Fasicularia -	- aurantium	- O. Pliocene. *Wh. Crag.*
Fenestella -	- antiqua -	- Carboniferous.
	Lonsdalei	- U. Silurian. *Wenlock.*
	membranacea	- Carboniferous.
	plebeia=retiformis (*characteristic*) -	M. Permian. *Mag. L.*
	sociale -	- U. Cambrian. *Lingula flags.*
Flustra -	- crassa -	- L. Eocene.

Heteropora -	- cryptopora	- U. Cretaceous. *U. Chalk.*
	ramosa -	- L. and M. Oolite. *Gt. and Cor. Oo.*
Hippothoa	- catenularia	- Post-Pliocene.
Lepralia -	- Peachii	- Post-Pliocene.
Lunulites -	- cretaceus	- U. Cretaceous. *U. Chalk.*
Oldhamia -	- antiqua	- L. Cambrian. *Longmynd.*
	radiata	- „ „
Polypora -	- sp. -	- Carboniferous.
Ptilodictya	- acuta -	- L. Silurian. *Bala.*
	scalpellum	- Silurian. *Llandovery and Wenlock.*
Synocladia	- virgulacea (*characteristic*)	M. Permian. *Mag. L.*
Thamniscus	- dubius (*characteristic*) -	M. Permian. *Mag. L.*
Theonoa -	- globosa -	- O. Pliocene. *Wh. Crag.*

Pteropoda.

Conularia -	- corium -	- L. Silurian. *Llandeilo.*
	ornata -	- M. Devonian.
	Sowerbyi	- Silurian. *Bala to Ludlow.*
	subtilis -	- U. Silurian. *Ludlow.*
Ecculiomphalus	- lævis -	- Silurian. *Llandovery and Ludlow.*
Theca -	- anceps -	- U. Silurian. *Wenlock and Ludlow.*
	Forbesii	- U. Silurian. *Wenlock and Ludlow.*
	operculata	- U. Cambrian. *Tremadoc.*
	corrugata	- L. Cambrian.
	triangularis	- L. Silurian.

Reptilia.

Anthracosaurus	- Russelli -	- Carboniferous.
Alligator -	- Hantoniensis	- M. Eocene.
	sp. -	- U. Eocene.
Cetiosaurus	- brevis -	- L. Cretaceous. *Wealden.*
	longus -	- U. Oolite. *Portland.*
Chelone -	- Bellii -	- L. Cretaceous. *Wealden.*
	Benstedi	- U. Cretaceous. *L. Chalk.*
	breviceps	- L. Eocene.

Crocodilus	champsoides	L. Eocene.
	Hastingsiæ	M. Eocene.
	toliapicus	L. Eocene.
	sp.	U. Eocene.
Dimorphodon	macronyx	L. Lias.
Dolichosaurus	longicollus	U. Cretaceous. *L. Chalk.*
Dolichosoma	Emmersoni	Carboniferous.
Erpetocephalus	rugosus	Carboniferous.
Emys	sp.	L. Cretaceous. *Wealden.*
	testudiniformis	U. Eocene.
Gavialis	Dixoni	M. Eocene.
Goniopholis	crassidens	U. Oolite and L. Cretaceous. *Purbeck and Wealden.*
Heraterpeton	Galvani	Carboniferous.
Hylæosaurus	Owenii	L. Cretaceous. *Wealden.*
Hyperodapedon	Gordoni	Trias. *Keuper.*
Ichthyerpeton	Bradleyæ	Carboniferous.
Ichthyosaurus	*genus*	Trias to U. Cretaceous.
	campylodon	U. Cretaceous. *L. Chalk.*
	communis	L. Lias.
	platyodon	"
	trigonus	U. Oolite. *Kim. Clay.*
Iguanodon	Mantellii (*very characteristic*)	L. Cretaceous. *Wealden.*
Labyrinthodon	(Amphibian)	Devonian to Trias.
	giganteum	Trias.
Lepterpeton	Dobbsii	Carboniferous.
Loxomma	Allmanni	Carboniferous.
Macellodus	Brodiei	U. Oolite. *Purbeck.*
Macrorhynchus	sp.	U. Oolite. *Purbeck.*
Megalosaurus	Bucklandi	L. Oolite. *Gt. Oo.*
	sp.	L. Cretaceous. *Wealden.*
Mosasaurus	gracilis	U. Cretaceous. *U. Chalk.*
Nothetes	destructor	U. Oolite. *Purbeck.*
Ophiderpeton	Brownriggii	Carboniferous.
Paleryx	sp.	U. Eocene.
Palæophis	toliapicus	L. Eocene.
	typhæus	M. Eocene.
Pholidogaster	pisciformis	Carboniferous.
Plesiosaurus	affinis	U. Oolite. *Kim. Clay.*
	Bernardi	U. Cretaceous. *L. Chalk.*
	dolichodeirus	L. Lias.
	sp.	Trias. *Penarth*
Pleurosternon	ovatum	U. Oolite. *Purbeck.*
Pliosaurus	grandis	U. Oolite. *Kim. Clay.*
Polyptychodon	interruptus	U. Cretaceous. *Gault and L. Chalk.*

Polyptychodon	continuus	L. Cretaceous.	*L. Gr.*
Protemys	serrata	L. Cretaceous.	*L. Gr.*
Protosaurus	Speneri	M. Permian.	*Marl-slate.*
Pterodactylus	Cliftii	L. Cretaceous.	*Wealden.*
	Cuvieri	U. Cretaceous.	*L. Chalk.*
Rhynchosaurus	sp.	Trias.	*Keuper.*
Steneosaurus	rostro-minor	U. Oolite.	*Kim. Clay.*
Streptospondylus	major	L. Cretaceous.	*Wealden.*
Thecodontosaurus	sp.	Trias.	*Bunter.*
Teleosaurus	asthenodeirus	U. Oolite.	*Kim. Clay.*
	Chapmanni	L. Lias.	
	sp.	L. Cretaceous.	*L. Gr.*
Tretosternon	Bakevillii	L. Cretaceous.	*Wealden.*
Trionyx	sp.	L. Cretaceous.	*Wealden.*
	incrassatus	U. Eocene.	
Urocordylus	Wandesfordii	Carboniferous.	

Rhizopoda (Foraminifera).

Bulimina	obliqua	U. Cretaceous.	*U. Chalk.*
Cornuspira	foliacea	Post-Pliocene.	
Cristellaria	rotulata	U. Cretaceous.	*U. Chalk.*
	Wetherellii	L. Eocene.	
Dentalina	acuta	L. Eocene.	
	communis	L. Silurian.	*Bala.*
	gracilis	U. Cretaceous.	*U. Chalk.*
Endothyra	sp.	U. Silurian.	
	sp.	Carboniferous.	
Eozoon	Canadense	L. Laurentian.	
Fusulina	cylindrica	Carboniferous and Permian.	
Globigerina	bulloides	Post-Pliocene.	
Lagena	ievis	Post-Pliocene.	
Nodosaria	*upwards from*	Carboniferous.	
Nummulites	lævigata	M. Eocene.	
	radiata	,,	
	scabra	,,	
Operculina	complanata	O. Pliocene.	*Wh. Crag.*
Polymorphina	communis	O. Pliocene.	*R. Crag.*
	Liassica	L. and M. Lias.	
Polystomella	striato-punctata	Post-Pliocene.	
Quinqueloculina	Hauerina	M. Eocene.	
	seminulum	Post-Pliocene.	

Rotalina -	- caracolla -	U. Cretaceous.	*Gault.*
	obscura -	M. Eocene.	
	ornata - -	U. Cretaceous.	*U. Chalk.*
Spirilina -	- infima - -	L. Lias.	
Textularia -	- *upwards from*-	Carboniferous.	
Triloculina -	- cor-anguinum -	M. Eocene.	

SPONGIDÆ.

Chenendopora	- fungiformis -	U. Cretaceous.	*U. Gr.*
Choanites -	- Konigi - -	U. Cretaceous.	*U. Chalk.*
Siphonia -	- pyriformis -	U. Cretaceous.	*U. Gr.*
Ventriculites	- decurrens -	U. Cretaceous.	*U. Chalk.*
	radiatus -	"	"
Verticillites	- anastomosans -	U. Cretaceous.	*U. Gr.*

PART V.

CHAPTER I.

Survey of Older Rocks—Boundaries and Faults—Downthrow—Vertical Section—Eruptive Rocks—Veins.

Survey of Older Rocks.—As an example of geological mapping which involves the application of nearly all the methods and operations described in the preceding pages, we may now take a district supposed to consist of palæozoic rocks. These being much older than those previously mapped (pp. 17 to 27, and figs. 5—8) are consequently much more likely to have been disturbed, faulted, and contorted. In mapping such rocks it is a good plan first to make oneself well acquainted with the physical geography of the district to be surveyed—to find out the watershed of the area, the system of its valleys, the highest points of its hills, and the amount of their elevation. We get therefrom a general idea of how the rocks, if not eruptive, will probably be found to run, for, as stated in Part I. (p. 15), beds almost invariably dip towards higher ground—to the form of which their inclination has indeed greatly contributed; therefore the contour of a hill approximately indicates the *local strike*, or rather *outcrop*, of the beds of which it is composed. In a country abounding in continuous escarpments, long ridges, and sweeping valleys we might naturally expect to find a tolerable consistency in the inclination of the strata; in a rugged broken surface we should see indications of sudden changes of dip, both in amount and direction, of faults, fractures, and contortions.

The next step would be to visit all the quarries, lime-kilns, brick-yards, or coal-mines, the existence of which we have been able to ascertain, and in all of them, by inspection and inquiry, obtain some useful information. By this means we get a good general idea of what the rocks of the district are, of the formation to which they belong, of their local nature and characteristics.

Assume all this to have been done, and that we are about to map in detail an area, the rocks of which consist of a Red Sandstone and a series of Limestones (? Permian) overlying the "Upper Coal-measures." We have visited the three quarries in the Sand and Limestones shown on the map, fig. 21, ascertained that in two instances the dip is due S. 10° and 14° respectively, due N. 5° in the third. This evidently indicates an anticline (or possibly a series of faults) which has brought up the underlying Carboniferous rocks nearer to the surface, and given origin to the valley by which they have been exposed (p. 36). To avoid confusion, the roads, &c., are omitted from the map, and the quarries numbered in the absence of other means of identification.

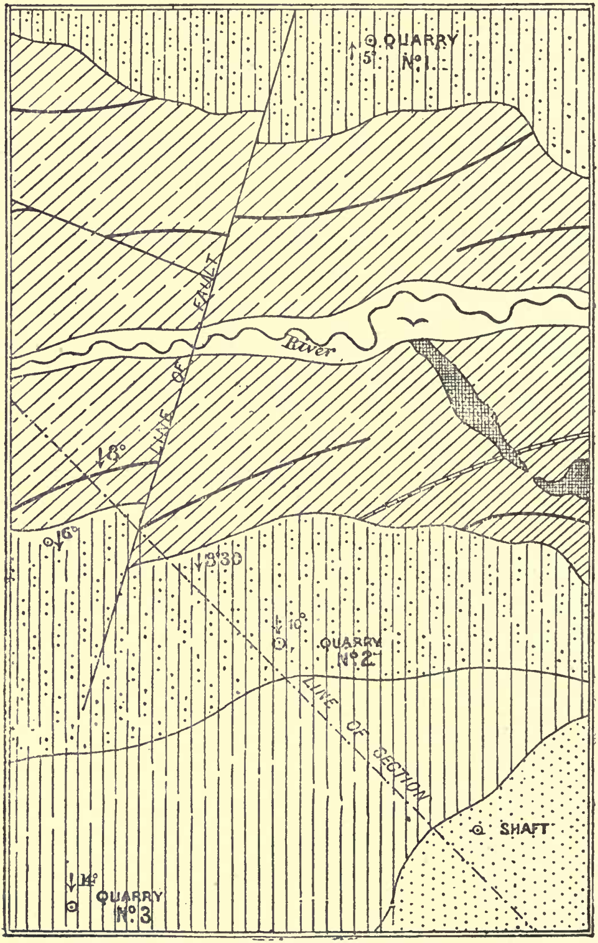
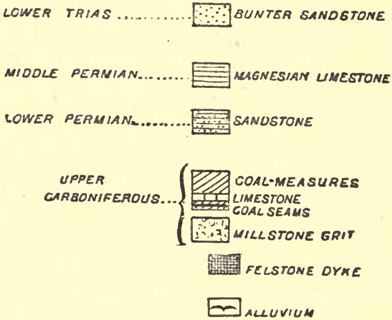


Fig. 21.—Scale 3 inches to 1 mile.

REFERENCE
TO FIG. 21.



In Quarries No. 1 and 2 we found sandstones, sand, and marl, with thin partings of shale, the latter slightly effervescent. The former were of a reddish-brown colour, very micaceous, and small patches of a whitish-looking rock, soft and minutely crystalline, were observed. This substance did not effervesce upon application of acid, and was scratched even by the nail; it is therefore Gypsum. Quarry No. 3 was being worked on an extensive scale for building purposes; the stone derived from it varied considerably in texture, might be readily scratched with a knife, effervesced slowly, and was of a grey colour. The compact beds were very fossiliferous, broke evenly with a dull lustre, and those of crystalline texture presented a conchoidal fracture and possessed a vitreous lustre. The rock is almost certainly Magnesian Limestone passing gradually into Dolomite, but the evidence derived from the fossils will be conclusive.

The notes taken in the quarries are recorded below:

Quarry (No. 1). Date . . . . 187 .

10 feet, brown and red sandstone or freestone, with red marl below; the surfaces of some of the beds are plainly ripple-marked.

Dip. N. 5°.

Quarry (No. 2). Date . . . . 187 .

30 feet, alternating and varying beds of micaceous sandstone and sand, indistinctly bedded, with shaley divisions and patches of gypsum. The uppermost part of this section is in a calcareous shale, with detached and weathered pieces of limestone (? Magnesian). Few fossils only occur; these are occasional pieces of a substance presenting a woody structure (? Coniferous), and in the shales above some fishes' scales. Dip S. 10°.

FOSSILS.

(In the Sand.) *Coniferous Wood.*
(In the Shales.) *Palæoniscus comptus.*

Quarry (No. 3). Date . . . . 187 .

40 feet, magnesian limestone, tabular and jointed, in beds from 2 to 4 feet thick, with thin earthy layers between. The upper beds are light-grey in colour, with many fossils and some concretions, also traces of ripple-marks. Lower down the stone gets harder and in some cases granular; the lowest beds are of

darker colour, more gritty texture, and in some parts distinctly crystalline.

Dip S. 14°.

FOSSILS.

Fenestella retiformis.	*Monotis speluncaria.*
Producta horrida.	*Schizodus obscurus.*
Camarophoria crumena.	*Bakevellia antiqua.*

Boundaries and Faults.—The boundary of the limestone is readily traced by indications here and there, and by rather sudden change of feature; the line runs just S. of Quarry No. 2; the shale and pieces of weathered limestone observed there are consequently the last remaining traces of the lower part of the Magnesian Limestone. But in walking over the S.E. corner of the sheet it was found to consist of a red or mottled sand; and in the only open section, the coal-pit shown on the map, the beds were seen to lie in a horizontal position. They must therefore rest unconformably on the limestone which dips S. at a high angle, and the direction of the boundary of the sand when drawn affords a similar indication. For instead of running even approximately parallel to that of the limestone, as it would if the two were conformable, it gradually approaches and would probably overlap it at a short distance farther to the E.

The line of the sand is next traced in the usual manner, and without difficulty, from the E. side of the sheet nearly to the W., where it seems to take a sudden and unexpected turn towards the N. Following this new line somewhat dubiously, and with no feature to guide us, we find that ere long the boundary resumes its old direction. There is something here to be accounted for, but drawing a dotted line to represent the uncertain portion, we leave it for the present and await further evidence. A small pit near the extremity of the sand shows the amount of dip there to be 6° only, but it is the same as the others in direction.

We now proceed to trace the outcrop of any coal-seams that may occur in the area, and, beginning on the W. side, follow one such line for a short distance, when the evidence of its course entirely ceases. But another line of outcrop commences from the north and south portion of the limestone boundary, and (where traceable) runs nearly in the same direction. When drawn, these two lines of coal-crop, in their direction and (where one ends and the other begins) in their distance from the limestone, look remarkably like two portions of one and the same seam. If they be so, the seam must have been dislocated by a *fault*, which would account also for the sudden deflection in the limestone boundary and the return to its ordinary direction. A line is drawn to represent provisionally such a fault, running through the ascertained *ends* of the coal-crops, and coinciding as nearly as may be with the doubtful limestone line previously dotted on the map. Further evidence may or may not be forthcoming.

In traversing the Coal-measures area, between that now surveyed and the river, we came across a mass of rock quite different in character. The notes of this and the mode of procedure connected therewith are deferred for the present, and will be found at p. 213.

On the N. side of the river the limestone does not come within the area; the line of the sand is run as before, but after tracing it for about half its length we meet with a break in it similar in every respect to that on the other side of the river. It seems also to be in the same direction or thereabouts; indeed it fits in with the provisional line of fault when the latter is sufficiently extended—there can now be no doubt of the existence of a dislocation. This fact is further corroborated by the coal-crops on the N., which behave exactly in a similar manner to those on the S., except that one portion of the line has been thrown back somewhat towards its former position. When the outcrop has been carefully mapped, it is found that this second throw can be explained in one way only—that is, by another fault, nearly at right angles to the first, passing through the broken ends of the coal-seam, as shown in the drawing, fig. 21.

Downthrow.—The amount of downthrow at any part of the fault can be easily calculated from the known dip and the lateral *shift* of the beds—where crossed by the line of section, at * fig. 22, it is 107 feet—the following being one method of its calculation. From * (in this case on the end of the unshifted part of the coal-seam) to the nearest part of the shifted portion (*i.e.* in the direction of the rise) the distance is 200 yards—the fall of the ground between, as ascertained by aneroid or otherwise, being 20 feet. By Table, Part II. p. 50, the depth below the surface attained by the coal-seam, with a dip of 8° in 200 yards (=600 feet), is 87 feet, which added to the 20 feet fall=107 feet, the amount of downthrow at the point *. The result would be arrived at, if the

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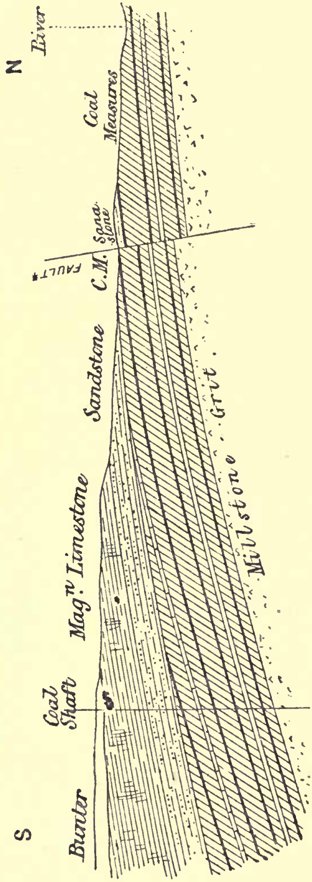
section crossed the fault at any other point, by ascertaining the depth beneath the surface, at such point, of each part of the broken coal-seam, or each part of the under surface of the sandstone calculated from its boundary.



Section, across Fig. 22. Bearing N. 45° W.

The dip of the beds in the section, fig. 22, is shown much less than it would be if the line of section coincided with that of the dip; in this case it deviates therefrom as much as 45 degrees. The variation and the method of determination of the difference are explained in Part II. In this example the dip of the limestone at its boundary is about 10° 30′, judging from that observed in the quarries on either side. By diagram the apparent angle, corresponding to 10° 30′, with 45° deviation, is 7° 30′ only, as drawn on the section; where the line of section first crosses the boundary of the sand the dip is 8° 30′, and this angle with the same variation shows 6° only, as represented.

The dip of the coal-seam, where first crossed has not been ascertained, but beyond the fault its dip is greater by 2° than that of the sand; on this side they must have the same *difference* in inclination, the seam therefore dips at 10° 30′—its apparent angle will be 7° 30′ where crossed by the section. The extremity of the sand where the line again crosses it is dipping 6°, apparent dip 4°, and the coal-seam 8°, which will be shown 5° 30′ only, on account of the deviation.

Vertical Section.—The beds shown in the section, fig. 22, could not have been continued to so great a depth from their outcrop (nor could the lower ones have been inserted at all) on the evidence obtained only on the surface, although even that would have furnished an approximation to the depth of the Coal-measures beneath the Bunter Sandstone; the additional particulars were obtained from the proprietor of the coal-mine, and are as given below.

. . . . Coal Mine, North Shaft.

To 100 feet.	Soft sandy stone, red and yellow. Level.
„ 460 „	Hard rock.
„ 740 „	Freestone.
	Shales.
At 800 „	"Three-foot" Coal, rising N., 3′ 3″ thick.
	Shales and Ironstone layer in the middle.
„ 920 „	Bed of hard blue stone, 8′ thick.
	Shales.
„ 1080 „	"Thin Coal," rising North, 1′ 6″ thick.
	Shales.
„ 1400 „	"Lower three-foot" Coal, 3′ thick.
	Shales.

At 1280 feet. Fire-clay, 4′ thick.
Shales.
„ 1560 „ "Bottom Coal," rising North, 1′ 3″ thick.
Shales.
„ 1640 „ Grit—"Farewell Rock."

All the layers below the Freestone rise North at about 15°.

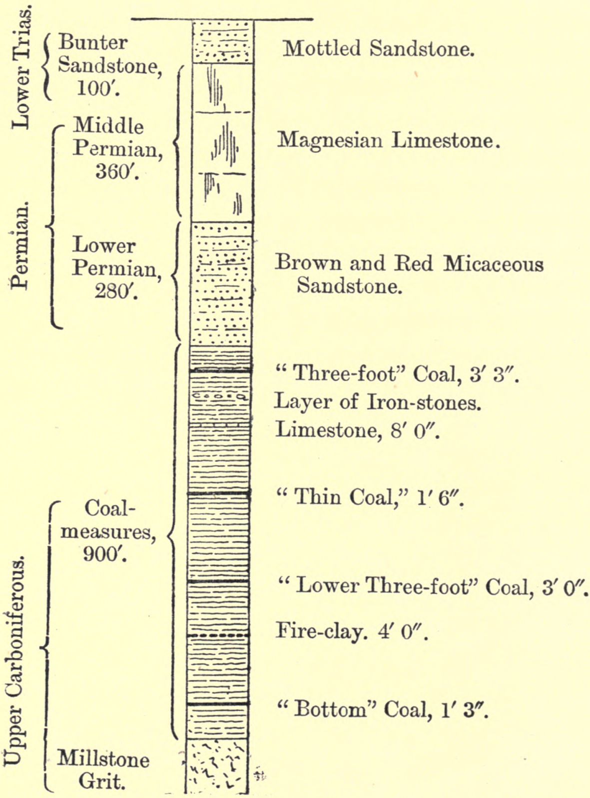


Fig. 23.

Note.—The particulars of the coal shaft when drawn to scale, and with the beds assigned to their proper formations, constitute what is called a "Vertical Section" (fig. 23).

By drawing the section (fig. 22) at the surface, from all the dips and particulars obtained, then inserting the data from the coal-shaft in their proper position (with the dips reduced for deviation of the line), we have no difficulty in correlating the beds and uniting the ascertained points in their planes of stratification. The coal-seam which comes to the surface where the section crosses the fault is thus shown to be the "Thin-coal" at 1080 feet; the one above it, at 800, is doubtless the seam that crops out on the E. side of the area.

Eruptive Rocks.—The rock of different character met with in traversing the Coal-measures area, p. 208, was first seen in a wall-like terrace running in a N.W. direction; all its outer surface was weathered almost to whiteness. With some trouble a specimen is detached which shows the rock beneath the weathering; this is grey in colour, does not effervesce under acid, and can be scratched by a knife with difficulty, therefore it consists of silicates. It is compact in texture, even in fracture, and has a vitreous lustre; it is probably Felstone, and the mass is either eruptive or intrusive.

There is no difficulty in mapping the mass, as it makes quite a feature standing out from the softer and more easily-denuded Coal-measures; on one side only are there recent accumulations of rain-wash, but by these the feature is not obliterated. The rock proves to be not interbedded with the coal and shales, but an eruptive dyke breaking through the strata without the slightest conformity to their lines of stratification. In mapping the eruptive rocks (and intrusive also until proved to be interbedded) it should be borne in mind that they behave at the surface in an irregular manner, very similar to that of the glacial drifts; their boundary must be closely followed, while the remarks upon the drifts (at pp. 34 *et seq.*) may in these cases also be found of some advantage.

Veins.—The mapping of lodes or metallic veins is very similar, as these follow an irregular course; but it will usually be found that they make a surface feature, as an elevation or depression according to the varying hardness and dip of the beds or masses in which they occur.

CHAPTER II.

Geological Generalisation and Practical Results—Water-supply—Soils.

Generalisation.—A geological examination of a quarry may seem a trifling matter, and one from which no very grand results can be expected. But the knowledge thus obtained, as pointed out in p. 2, is not simply and strictly a local knowledge, for it extends a long way into and beneath the surface of the earth. We see, therefore, that examination of several such quarries must make us acquainted with the nature and position of the rocks a long way down over all the intervening area.

The geologist having, by careful and accurate observation of all available data, attained this knowledge of a district, and, viewing the whole tract at once, as upon a map, can in his mind lift up, as it were, formation after formation, and see those beneath as plainly as though they had never been covered. In imagination removing one series of deposits he sees beneath it the surface of another, which may or may not have been eroded previous to the deposition of the one thus removed. If it has not, he views its full extension, marks its gradually thinning boundaries, defined probably by lines of cliffs and of conglomerates, the ancient beaches; if denuded, he sees the exposed edges of the eroded strata, cut through by ancient valleys, and in places outliers only remaining to mark its former extension. Some parts of the old surface may be covered by sheets of lava, intersected by volcanic dykes, or perhaps dislocated by faults in every direction. He notes also the gradual approach of those variations in the conditions of sea, land and climate which ultimately lead to the deposition of the succeeding formation, and which drive before them, slowly but inevitably, the existing forms of life and bring in new races of inhabitants.

When the mind has grasped such facts as these, facts supported it may be by strongest evidence, the aim and end of our geological research has been mainly achieved. We can not always hope to carry our inductions to the extent here indicated, but it may done with very fair probability of accuracy within reasonable limits. And it is to this kind of knowledge that Geology must look for its practical result, in the assistance that it affords to mining, engineering, quarrying, and well-boring operations, although it cannot be denied that the scientific gain in itself possesses the greatest attraction.

To work out a very simple problem of the kind, let us take the small tract surveyed in Part I., showing Reading-beds, Chalk, Upper Greensand, and Gault; the last being, within the area, the lowest formation. Remove all the others and we shall see a tract of sea-bottom, on which "stone-lilies" grow and Nucula pectenata flourishes; their remains being eventually entombed in the increasing sediment. But the area is slowly rising, and as the water decreases in depth the animals migrate seawards, and others whose habitat is shallow water gradually come in. One part of the clay, beyond the map, is already well above the water, and the new kind of sediment, sand, thins out against the somewhat denuded barrier—the animal remains washed from out the Gault being reburied with those belonging to the Upper Greensand.

The land again goes down, and continues sinking for a lengthened period, during which the Chalk, with its deep-sea fauna was slowly deposited. The Chalk was formed in two divisions, upper and lower, with probably a denudation between; the upper part had deposited with it and disseminated through its mass a large amount of silica; this afterwards segregated itself and closed in as it were upon any organic fragments containing silica, and thus formed the flint concretions. Then began a long period of denudation which wasted the Chalk, and left many flints upon its surface embedded in the resulting stratum of clay, noted at the base of the Reading-beds in the sections. This was succeeded by the deposition of the shallow water and fluviatile Reading-beds, which thin out against the higher part of the Chalk, and rest unconformably upon that formation.

Very great and important generalisations in geology have been made from scientific observation of the character and mode of occurrence of beds at distant points, bringing all apparently discordant features into one harmonious whole, with sometimes grand and unexpected results. As an example may be cited Professor Prestwich's arguments in favour of obtaining a supply of water for London from the Lower Greensand.* These affirm the probable existence of that formation beneath the metropolis, in a water-bearing condition, and are based upon the physical conditions of its outcrop many miles away from the point in question. The conclusions have been amply justified so far as the reasoning is concerned, and although the Lower Greensand has not been found under London, it is owing to what may be called an accidental circumstance, which has, however, given rise to another important generalisation. That is the underground extension of a ridge of Palæozoic rocks which rise up sufficiently high to reach the Gault, and thus to cut out the Lower Greensand, that otherwise must have been there.†

The Secondary rocks were, of course, deposited in a fairly level position, and in this area have not since been subjected to much disturbance. They should consequently be found, when not thinned out, in regular sequence; and if a tract of high ground existed in the

* "Water-bearing Strata of the London Basin."

† "Account of the Kentish-town Well-section." Prestwich: *Quart. Jour. Geol. Soc.* vol. xii. p. 9.

area of their deposition, the beds must abut on the flanks of such elevation. Also if such high ground consists of the *lower* part of any series, the upper members should also be found on either flank, with their denuded edges covered by the newer formations. Mr. Godwin-Austen has shown that if the rock underlying the Gault beneath London be, as it probably is, Old Red Sandstone, then the Coal-measures, the New Red Sandstone, &c., must occur on either flank of the anticlinal that has brought it up to that position. That, in fact, the ridge is part of an extension of the South Wales anticlinal to that of Belgium, therefore the Coal-measures must occur on either flank, and will probably be found, as in those areas, at a moderate depth, unless removed by an ancient denudation.

The way in which geological knowledge and reasoning may be turned to practical account is shown also in the two following sections—on Water-supply and Soils—selected from many subjects upon which their bearing is of great importance.

WATER-SUPPLY, &c.

An improvement in the water-supply of a district is one of the practical results that may be expected to arise from the working out of its geological structure—that is, from the knowledge obtained of its rocks and of their relation to each other. The phenomena of springs and the sources of supply to artesian wells are so entirely dependent on stratigraphical and physical features that an acquaintance with their principles can not fail to be of use to the student of "Field Geology."

The subject may be advantageously divided into three sections:

1. Origin of the supply.
2. Streams and springs. (*Natural founts.*)
3. Wells. (*Artificial founts.*)

1. *Origin of the Supply.*—The original source whence is derived all our supply of water—whether it come to our hand through natural or artificial founts—is, of course, the "Rainfall." This varies every year and in every locality, but is always and everywhere (with rare exceptions) much in excess of what is actually necessary to the population. Then, it may be asked, "how is it that our supply ever seems likely to be unequal to the demand?" The answer is simple. We do not economise that derived from the natural founts, and we do not sufficiently avail ourselves of the artificial founts, which are at all seasons practically inexhaustible. The following statistics, concerning England, will help to elucidate the matter.

Thirty gallons per day or 50 tons per year is the average quantity required for each head of the population. One inch of rainfall to one acre is equal to 100 tons. There are $1\frac{1}{2}$ acres to each head of population.

Therefore a quantity equal to a rainfall of only *one-third of an inch* is sufficient for the requirements of the population.

The *minimum* Rainfall is about $27\frac{1}{2}$ inches. The average Rainfall is about 34 inches. In dry years (in some localities) it has been but 16 inches. In wet years (in other localities) it has been even so high as 20 feet. This excessive rainfall occurred in the Lake District, in 1872; in the Southern and Eastern counties, in the same year, it was 27 inches. The rainfall of 1872 was 36 per cent. above, and of 1870 18 per cent. below the average.

One very large portion of the rainfall runs away in rivers to the sea; another is given back again by evaporation. But in every year and in every locality there remains, as stated above, a quantity which, economised and utilised, would be much in excess of our requirements. And this quantity finds its way into the hidden recesses of the earth, to be given or drawn forth from the natural and artificial founts described in the following sections (2 and 3). In proportion to the size of the collecting area will be the quantity, and according to the nature of the strata through which it passes will be the quality of the water supplied.

2. *Streams and Springs.*—The water-supply of a district is not, by any means, necessarily proportionate to its rainfall. So much depends upon its physical geography, its height above the sea, and especially upon the nature of its soils, subsoils, and underlying strata. So far as natural founts are concerned, the valleys will be better off than the hills, and the low-lying districts than those of greater elevation; while permeable soils and subsoils receive, and for a while retain, a much larger quantity of water than do those that are impermeable. For, as the rain falls on the ground, it is drawn by the law of gravitation to a lower level; if the surface be impervious, it runs off by the ditches and rivulets to the larger rivers, and thence to the sea. If the surface be wholly or partly pervious, a portion only

runs to the rivers, the rest being absorbed by the water-bearing strata, and again thrown out at a lower level, in the form of springs, on the hill-sides; or, the conditions being favourable, it is retained by those strata at various depths, which thus are constituted huge underground reservoirs. (Section 3.)

The supply from the natural founts will vary as the seasons; in periods of drought the streams run dry, and the springs fall off, while shallow wells, which derive their water either by soakage from a stream or from a so-called land-spring, become exhausted in consequence. Neither streams nor springs should be depended on for a supply of water, not only on account of their intermittent nature, but because of their liability to pollution.

The strata that now throw out springs would, if occurring at a different level or if inclined at a suitable angle, become the means of draining water from the surface, and the springs of one locality are, in fact, but the natural drainage of another.

3. *Wells.*—This section involves the "theory of springs," and relates to *artesian* or deep wells and borings, and it may be illustrated by performing in imagination a simple experiment. Take two shallow dishes and place one on the other with a thin layer of sand between them; pour in water at one edge of this layer, and it will be found that in a very short time the sand is saturated alike throughout. A portion of the water has, in fact, first descended by gravitation under the centre of the upper dish, then risen to the other edge of the sand, through the force of hydrostatic pressure, to the same level as that at which it entered. A

hole being bored in any part of the upper dish the water will rise through that hole until it stands at the same level. If the upper dish were filled with clay or any other impervious material, and a hole were bored through, the water, of course, would rise in the hole in a similar manner.

Here are all the phenomena of deep-seated springs and artesian wells. For what occurs on a small scale in the sand confined between the dishes occurs in nature in pervious strata confined between those that are impervious, and the water rising in the hole represents exactly an artesian well. The water-bearing bed may be not absolutely continuous, but the same results will follow so far as the continuity be unbroken; or there may be outlets at a lower level than the outcrop, when perennial springs are the result. These springs affect the main supply in the same proportion only as the discharge from them bears to the amount of rainfall received at the outcrop.

When a boring is made at a place situated at a level lower than that of the outcrop of the water-bearing stratum, the water rises *above* the surface; this is the case at several deep wells in the valley of the Lea, sunk down to beds of sand and pebbles which come to the surface at a higher level several miles to the northward.

It follows that when all the conditions of dip, permeability, and continuity are known, it becomes a matter not of speculation but of certainty to estimate the depth at which water will be found, and the height to which it will rise in the well.

It may be repeated that the water-supply of a district is not by any means proportionate to its rainfall. The water-bearing beds are great distributors, and by them the supply is to a great extent equalised. The supply to be obtained by boring down to deep-seated springs is practically inexhaustible, being scarcely, if at all, affected by drought, and these springs form the only source on which can be placed a full reliance.

Soils.

All soil or mould has been produced during the lapse of many ages by the disintegration—arising chiefly from the action of rain, frost, and other atmospheric influences —of the exposed surface of the strata which form the base or subsoil. It has been increased in depth by the annual growth and decay of vegetable matter, assisted by the apparently trifling, but still ceaseless, action of earthworms, working into and turning up the subsoil. It is thus evident that the nature of the soil of a district must strictly depend on that of the subsoil from which it is directly derived, and as the strata, or rocks, forming the subsoil, present many varieties, they give rise to subsoils and soils that differ in a corresponding degree.

The composition of soil is very variable—is greatly dependent on that of the subsoil, by the decomposition of which it has been formed—and bears to the subsoil a nearly constant relation. An average soil consists of silica, alumina, lime, magnesia, oxide of iron, small quantities of ammonia, carbonic acid, and alkaline and earthy salts, with a portion of decaying organic matter. The nature and fertility of the soil varies as these constituents are present in a greater or less degree, all being to some extent necessary for the proper development of plants, but some, in excess, are injurious to vegetable growth; for instance, soils containing much sulphate of iron are invariably unproductive.

A base of gravel produces a light soil abounding in silica—that substance not unfrequently forming more than four-fifths of its whole weight—and which varies from a fine sandy mould to a stony soil as the particles of the gravel beneath are in size fine and uniform or coarse and irregular. Sand makes a similar but somewhat finer soil. Clay gives rise to a stiff, heavy, and sometimes tenacious soil, consisting mainly of alumina, varying in quality and appearance perhaps more than any other kind, but being generally more productive.

The nature of the subsoil itself also bears to the geology of a district a relation equally constant. The subsoil of any locality situated on a formation of reasonable thickness must partake of the nature of that formation, whether it be Lime, Sand, Clay, or any other rock. And this applies not merely regarding those substances as generally understood, but also when they occur in a compact state, as Lime stone, Sandstone, Shale, &c. Therefore, the geology of a place being known, the subsoils and soils are more or less understood.

There are certain other natural causes which modify, to some extent the nature of soil; the results of the influence exerted by these causes being comparatively small, but economically important. They are—1. The rain-wash, which removes the particles of soil from higher to lower ground. In a flat country the effects of this action are not very perceptible; but where the surface is broken by hills and small valleys, accumulations, several feet thick, may often be seen. Also, where the downward progress of rain-wash on a hill-side has been arrested by a fence, its result is—after a few years—very evident, in the ground being unduly higher on the upper than on the lower side. 2. The annual growth and decay of vegetation, which is the most important of the modifying causes. The plants that have lived and died upon the soil, from the time when the first thin layer was formed on the exposed surface of the subsoil, have all (minute as they are in many instances) performed a useful part, by absorbing from the air carbonic-acid, water, and ammonia. They yielded to the soil, by their own decay, these substances which form its organic constituents. The proportion of decaying vegetable matter in soils is usually small—about one-fiftieth—but sometimes it is excessive—as in peat—and the soil rendered thereby almost worthless for purposes of cultivation. 3. The matter derived from animals living on, above, and beneath the surface, and from their ultimate decomposition. All wild creatures—birds included—thus naturally contribute to the fertility of soil, to an extent perhaps much larger than is generally appreciated.

INDEX.

ERRATA.

Page 15, line 18, *for* any *read* all.
,, 17, ,, 18, *for* two slips *read* slips.
,, 24, (fig. 7), *for* 7° *read* 3°.
,, 25, line 19, *for* hollow *read* hollows.
,, 28, ,, 10, *for* prove *read* proves.
,, 33, lines 22, 25, *for* montonnées *read* moutonnées.
,, 70, line 7, *for* will then be *read* will have been.
,, 71, *for* Top of Church Escarpment *read* Top of Chalk Escarpment.
,, 82, line 4, *after* transferred *insert* by parallel rule.
,, 87, *insert footnote :* * Metals and Minerals, as constituents of Rocks, are, for convenience sake, included under this heading, Lithology.
,, 94, line 6, *omit* its.
,, 155, ,, 12, *insert* if *between the words* while *and* these.
,, 156, ,, 4, *for* trelobites *read* trilobites.
,, ,, ,, 5, *for* lingula flags *read* Lingula flags.